LECTURES

ON

MINING

DELIVERED

AT THE SCHOOL OF MINES, PARIS

BY

J. CALLON

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TRANSLATED AT THE AUTHOR'S REQUEST

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AUTHOR'S PREFACE.

I NOW present to the reader the third volume of the *Lectures on Mining,* delivered at the School of Mines by M. Jules Callon. Madame Callon has been pleased to entrust me with its publication, having already done me the honour of confiding that of the third volume of the *Cours de Machines* to my hands. The spirit in which this volume has been edited differs somewhat from that in which the preceding one was prepared.

Indeed, there appeared to me to be certain chapters which could only draw their value from the thoughts and wording of him who taught them, and who alone was able to imprint his personal stamp upon them. I have therefore simply copied their titles, which M. Callon drew out only a few days before his death, and I have transcribed word for word the short summaries of the corresponding lectures.

I have thought proper, on the other hand, to treat the important but altogether special question of mechanical preparation in a thorough manner, although it has been necessary for me in this case to modify to a certain extent the notes that have been handed to me, in order that I might make them harmonize with the most recent advances that have been made in this branch of the art of mining.

The information which I myself collected last year (1877) during a tour in Germany, and the notes brought back by several engineers or pupils of the *Corps des Mines* from their missions in England and in the United States, have, I hope, enabled me to attain the object which I had in view.

E. BOUTAN.

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LECTURES

ON

MINING.

CHAPTER XXI.

ACCIDENTS IN MINES.—MEANS OF SAVING LIFE.

(608) What has been said in the preceding volume regarding ventilation and safety lamps naturally leads us to say a few words about accidents, which happen too often, and involve the safety of life and property on a larger or smaller scale, according to circumstances.

Independently of accidents affecting single individuals, such as falls of ground, blasting, &c., it is necessary for us to refer to:

A.—Explosions of Firedamp.
B.—Underground Fires.
C.—Inundations.

A.—**Explosions.** These are the kind of accidents which most frequently produce great catastrophes.

Their effects vary according to their violence:

(*a*) The effect may be local, and unfelt in the rest of the workings.

(*b*) The effect may be violent, and felt everywhere.—Direct blast.—Return blast. The workmen are crushed to death; but most of them are suffocated.—The trap doors and stoppings are broken or displaced.—The timbers are knocked out; and, as a

consequence, falls take place, and the ventilation is destroyed or endangered. Lastly, there are possible dangers to be apprehended after an explosion.—Timber set on fire, and succeeding explosions.

Single shafts divided into compartments a special source of danger.

MEANS OF PREVENTION.—Above all, good ventilation. The ventilation to be varied according to requirement. For example, if the barometer falls.

MEANS OF LOCALISING THE EFFECTS.—Substantial stoppings, safety doors, &c.

MEANS OF REPAIRING THE DAMAGE.—To restore the ventilation by following the course of the fresh air, putting up temporary doors and stoppings, &c.

B.—**Underground Fires.** The timber is accidentally set on fire, by a shot, an explosion of firedamp, a badly-arranged ventilating furnace, &c.—But the most ordinary case is that of spontaneous combustion, originating in old workings, or in falls, or even in shaken and fissured ground resting upon the stowing, &c.

MEANS OF AVOIDING THEM.—To send out all the shale.—To prevent the occurrence of falls.—To remove everything that is liable to heat.—Not to make too many slices when working with stowing.

MEANS OF EXTINGUISHING THEM.—To dam off the district, and circumscribe it as much as possible.

LAST RESOURCE.—To flood the mine.—Troubles arising from this when the workings are reopened.

C.—**Inundations.** Means of avoiding them. Boring holes in advance. Precautions used in tapping water from old workings.

SUCCOURING THE WORKMEN.

Ingenious means and apparatus for penetrating into the foul air.—Small ventilating machines.—Ventilating pipes ready in the store. Rouquayrol's and Denayrouze's apparatuses.* The workmen can live a long time. There are some examples of thirteen days.

* Fleuss apparatus.—*Translators.*

First measures to be taken:

FOR THOSE SUFFERING FROM BURNS.—Prevent contact of the air.—Wadding.—Cold water.—Goulard water.—Warm baths.—Internal injuries often more serious than the external ones.

FOR THOSE SUFFOCATED BY FOUL AIR.—Place them in the open air. Dash cold water on them, and apply smelling-salts or ammonia to the nostrils.

FOR THOSE APPARENTLY DROWNED.*—Keep them warm, with the head high, lying on their sides. Rub them with camphorated spirit of wine. Restore warmth to the skin. Make them breathe ammonia, and swallow a small quantity of warmed wine.

* Produce artificial respiration. *See* Shepherd's *First Aid to the Injured*, published by the St. John Ambulance Association. (Price 1s.)—*Translators.*

CHAPTER XXII.

ARRANGEMENTS AT THE SURFACE.

(609) A. **Haulage from the mouth of the mine to the point where the waggons are emptied.**

α. On the level.

β. Downhill. Ordinary inclined planes. Double-acting inclined planes, much used at the Grand-Combe mines. Balance-pits. Combination of a shaft and a level.

γ. Uphill. Raise the mouth of the shaft, or the level of the platform on which the waggons are received, by means of a scaffolding. Employ the winding-engine for the purpose of performing the accessory service of raising the waggons to the required height, either by drawing them up an inclined plane, or by raising water for working a water-balance, or have a small separate steam-engine connected with the same boilers as the large one.

B. **Emptying the waggons or corves.**

The waggons having been brought to the pit top and conveyed along the surface, require to be emptied.

The following operations are necessary:

1. Overturning the waggon. Various kinds of tipping-machines. Emptying the large kibbles employed at Mons, already described Marsaut's tipping-machine. (See Ponson, Plate XLV.; Burat, Plates III. and IV.; Combes, Plate XLVI.)

2. Picking.

3. Screening. (See Ponson, Plate LXI.; Burat, Plate XXVI.)

4. Loading for sending off. (See Ponson, Plate LXIII.) This is done in two ways.

Distinguish the two leading principles:

a. For economy of labour. (Newcastle, Mons, &c.)

β. For saving the large coal, facilitating the picking. (Grand-Combe, &c.)

The choice to be made depends on commercial considerations, on the hardness of the coal, on the larger or smaller proportion of stones, &c.

NOTE.—The part of this chapter referring more particularly to the mechanical preparation of coal will be fully treated further on.

CHAPTER XXIII.

ON THE MECHANICAL PREPARATION OF MINERALS. GENERAL CONSIDERATIONS.

(610) It has been shown in the previous chapters how the raw products of a mineral deposit are brought to the surface, and we have described with all the necessary details the separate operations which are required for producing this result, and especially the breaking down, hauling, and winding. We have also given particulars of the accessory but indispensable operations of pumping and ventilation.

The *rôle* of the miner proper is brought to a conclusion at this point, but that of the mine-owner goes further. After the minerals have been brought out of the mine, they have often to undergo certain operations before they are in a fit state to be sent to the market, or to the smelting works where they are treated. These operations, which are sometimes very simple, sometimes very complex, are known under the general name of *mechanical preparation* or *dressing*.

They are as follows:

For coal, a process of washing, for the purpose of separating stones and pyrites from the small coal.

For iron ores, a process of washing, in order to separate clayey matters.

For other metallic ores, a series of operations, with the object of removing as far as possible the veinstuff or barren rock, and of separating from each other the minerals of various kinds that are often met with in the same lode.

(611) The dressing carried out in this way increases the market value of the product, but reduces its weight to a greater or less extent, according to circumstances.

The mine-owner ought always to ask himself the question, when dressing is not indispensable, or, in other words, when the raw product is *saleable* without it, whether the advantages he expects to derive from the operation will compensate him, or more than compensate him, for its cost, and for the decrease in weight which it will entail, either by the elimination of sterile substances, or by loss of the useful mineral itself, which always escapes to some extent.

The advantage generally consists not only in the production of an article of intrinsically higher value, so that the ton of useful mineral sells for a higher price in the second case than in the first, but also in a notable saving in the cost of transport when the ore has to be sent to more or less considerable distances.

Independently of the fact that the dressed product is often much more readily saleable, these considerations ought to be scrupulously weighed by the owner of a mine, and the results calculated in a careful manner, so that he may ascertain how he may derive the greatest amount of profit; and this, after all, is the object in view.

(612) This calculation is easy enough, if we know the loss caused by the operations to which the mineral is subjected.

We will take coal, for example, and endeavour to find out what are the conditions under which it is the interest of the mine-owner to wash it.

We shall designate the price of the raw coal per ton by p, the price of the washed coal by P (both sorts being considered as delivered at the point where they are to be used), and by Q the cost of carriage per ton. Then the value at the mine will be:

$p - Q$ per ton of raw coal;
$P - Q$ per ton of washed coal.

If we represent by q the extra cost of producing a ton of washed coal, and by γ the loss per ton which always takes place in con-

sequence of the removal of shale, as well as by the escape of fine coal along with it, the value per ton of washed coal at the mine is evidently:

$$P - Q - q;$$

and the value of the washed coal produced from one ton of unwashed coal is:

$$(P - Q - q)(1 - \gamma)$$

But the condition that must be realised, in order that it may be worth while for the mine-owner to undertake the washing, is evidently that the washed coal produced by a ton of raw coal shall be worth more money, taking the cost of washing into account, than the ton of unwashed coal from which it is produced. That is to say, we must have the relation:

$$(P - Q - q)(1 - \gamma) \geqq p - Q. \qquad (1)$$

If we deduce the value of P from the above expression, we can ascertain the lowest price at which the coal can be sold, and decide whether we ought to wash or not. We shall see that it is nearly always a great advantage to wash the coal.

It is true that in many cases, and apart altogether from the cost of carriage, the circumstances of the market may be such as to compel a mine-owner to wash his coal, and this, not because he will derive more benefit by so doing, but because his produce would be of very small value—perhaps *unsaleable*—without it. It may then be his interest to make a sacrifice in the expense of washing, and strictly speaking it may even happen that a mine-owner will derive a profit so long as the cost of washing is not greater than the selling price.

(613) As to the value of γ, or of the loss, we may say that it is a very variable quantity, and that the variations depend on many causes; amongst which, those that occupy the first rank are, the care with which the operation is conducted, the character of the appliances, and lastly, the amount of refuse or ash extracted, which we shall call α, and the amount of refuse or ash left in the coal, which we shall call β.

If we suppose that all the matter extracted by washing is waste, and contains no coal—a case that is generally far from the reality,

since it would make it necessary not only that the shale was free from coal, but also that no pure coal escaped along with it—then by equating the quantities of pure coal before and after washing we obtain the following relation between a, β, and γ:

$$1-a=(1-\beta)(1-\gamma);$$

whence

$$1-\gamma=\frac{1-a}{1-\beta}.$$

If we know the values of a and β, we can obtain from them the value of γ approximately.

Let
$$a=0{\cdot}25,$$
$$\beta=0{\cdot}10;$$

Then we have

$$1-\gamma=0{\cdot}86.$$

We could then take 0·80 as the value, making allowance for losses due to coal carried away, and then replacing γ and q by their values, we can transform the expression (1) given above as follows:

$$P-Q \geqq 1{\cdot}25\,(p-Q)+1,$$

This will serve equally well with the first one as the conditional equation.

(614) We may now leave the foregoing question in order to ask whether the interest of the consumer is the same as that of the producer; but it is easy to see that it is not the same, and that his manner of calculating the price he should give for the washed fuel is decidedly different.

In fact, while the former tries to obtain the same total amount of profit from the product of the mine, the latter wishes to pay only for the useful part of that product, or, in other words, for the pure coal; and if we still designate by a the amount of ash contained in the raw product, we see that he will pay for a ton of pure coal—

$$\pi=\frac{p}{1-a}.$$

Again, if after being washed the coal still contains a proportion β of ash, the consumer would not care to pay for the ton of washed coal more than—

$$P=\frac{p}{1-a}(1-\beta);$$

Or in supposing, as above, that—

$$\alpha = 0{\cdot}25,$$
$$\beta = 0{\cdot}10,$$

Then $$P = 1{\cdot}20p.$$

In other words, it makes no difference whether the consumer pays p for the raw coal, or 1·20 p for the washed coal. But the latter price must evidently be a minimum, for although the consumer pays more for the useful mineral, he gains all sorts of advantages by having it freed from the greater part of the useless or deleterious substances with which it was formerly mixed, inasmuch as these might in many cases injure the quality of the manufactured products, entail extra expense in smelting, if they have to be melted into slag, or, lastly, choke up the fire-bars or eat them away, and so materially increase the cost of keeping them in repair.

(615) Considerations of the same kind will enable the producers of metallic ores to calculate approximately how much they can afford to spend in dressing the ores; however, in this case the amount of the loss is frequently not known with any exactness.

We may take lead ore as an example, and suppose it to be bought at a price determined by the following known formula:

$$P = A^{fr}\frac{x-7}{100} - 70^{fr} - \frac{x-7}{100} \times 60^{fr} + \frac{x}{100} \times 10y \times 0{\cdot}21^{fr} \times 0{\cdot}96.$$

This formula is obtained by subtracting from the price of the lead, added to that of the silver contained in it, a first sum of 70 francs for the cost of smelting, then a further sum of 60 francs per ton for the cost of its treatment by Pattinson's process. In this formula—

A is the price of a ton of lead.

x the yield of the ore, by assay, from which seven units are subtracted for loss in smelting.

y the yield in silver in grammes per 100 kilos., taken in this case at the value of 0·21 franc per gramme. Its value has however fluctuated greatly during the last few years.* This yield is reduced in the last term of the equation in the ratio of 0·96 to 1 in order to make allowance for loss in smelting.

* The average value of *standard* silver in London in 1885 was only 48⅝d. per oz., and 1 gramme of pure silver would consequently be worth only 0·176 franc.—*Translators.*

This formula gives the price of the ore at the smelting works, but it is necessary to diminish it by the cost of transport F in order to obtain its true selling price at the mine.

Take for example: $A = 500$,*
$F = 30$,
$y = 600$,

then the value of a ton of ore at the mine will be:

$$(5 - 0{\cdot}6 + 12{\cdot}1)\,x - 35 - 70 + 4{\cdot}20 - 30\,;$$

that is to say— $16{\cdot}5x - 130{\cdot}80$,

or $16{\cdot}5^{\text{fr}}\,(x - 7{\cdot}93)$.

From this expression we see that, for the values we have assumed for A, F, and y, the co-efficient of the parenthesis, which may be called the value per *unit of yield,* is $16{\cdot}50^{\text{fr}}$, and that if the ore does not contain 7·93 per cent of lead it is of no value.

We may further conclude from this:

1. That $16{\cdot}50^{\text{fr}}x - 130{\cdot}80^{\text{fr}}$ is the limit of the cost that may be incurred for separating a ton of ore with a yield x from a lot of poor stuff.

2. That $130{\cdot}80^{\text{fr}} - 16{\cdot}5^{\text{fr}}x$ is the limit of the cost that can be incurred for eliminating a ton of poor stuff with a yield x from amongst a lot of richer stuff.

(616) In a general way, if we take V as the value of a ton of ore, we shall obtain an equation of the following form by means of the formula given above—

$$V = Mx - N.$$

If $Mx - N$ is greater than zero the ore has a certain marketable value. In the opposite case it has none; in the raw state it is unsaleable refuse, but in certain cases it might be worth while to endeavour to treat it so as to extract the useful matter from it.

Further, if we suppose B tons of ore with a mean yield x, separable into B′ tons with a yield x', and B″ tons with a yield x'' in such a way as to furnish the two equations—

$$B = B' + B'',$$
$$Bx = B'x + B''x'',$$

* The average value of pig lead in London in 1885 was only £11 16*s.* 10*d.* a ton, and not £20, the price in 1877.—*Translators.*

we have

$$V = B(Mx - N),$$
$$V' = B'(Mx' - N),$$
$$V'' = B''(Mx'' - N),$$

and consequently

$$V' + V'' = (B'x' + B''x'')M - (B' + B'')N = V.$$

If V and V′ are positive, and V″ negative, then V″ will be the greatest expense that can be incurred for separating B″ tons of poor stuff from the total mass. If, on the contrary, we suppose V and V′ to be negative, and V″ positive, then V″ will be the greatest cost that can be incurred for extracting the B″ tons of rich ore that exist in the whole lot of stuff.

The quantity M is the *value of the unit of yield* or *unit per cent.* We have seen that with the values given above for A, F, and y the unit per cent. is worth $16{\cdot}50^{fr}$, and this is naturally a lower value than that of the metals which it contains, which we assumed in the foregoing case to be $17{\cdot}60^{fr}$, or say:

10^{k} lead at $0^{\cdot fr}50$	$5^{\cdot fr}00$.
60^{gr} silver at $0^{\cdot fr}21$	$12^{\cdot fr}60$.

(617) Similar considerations can be applied to copper, tin, &c.; but it behoves us to add that although they may serve as a guide to the mine-owner, they should not be his only rule, for they do not take into account an important element of the question, that is to say, the loss in dressing.

But this loss, which is often considerable, cannot be determined exactly;* partly on account of the great difficulty, not to say complete impossibility, of obtaining a proper sample from the mixture of large and small ore, more or less covered with mud as it comes from the mine; and partly on account of the difficulty of determining how much useful ore is lost, either in the form of small specks attached to pieces of refuse, or in the form of minute particles or thin leaves which are carried away by the water during the process of washing.

In conducting dressing operations, and in judging how far he can usefully carry them, the engineer must apply all his tact and experience.

* The loss in dressing is sometimes ascertained with a fair degree of accuracy.—*Translators.*

By enriching his produce too much, he will increase the value of each unit per cent., but he will incur a more or less considerable loss, which, taken together with the extra cost of washing, may counterbalance or outweigh this increase in value.

On the other hand, if he does not enrich it enough, admitting always as an indispensable condition that his produce is still *marketable,* he may have an article of depreciated value, not readily saleable. But more than this, and above all, the deduction of a constant number of units in calculating the selling price, as we saw in the case of lead ore, will cause him to lose a greater proportion of the value with a poor ore than with a rich one.

It is therefore very important to know how to steer a middle course between these two extremes, and this we are enabled to do by making experiments, and calculating the profit in each case.

(618) The foregoing remarks show how we may realise the economic importance of mechanical preparation or dressing. We shall now proceed to examine the technical processes which are in use for carrying out this operation; and we shall begin with the most complicated case, namely, that of metallic ores, and proceed later on to the consideration of the washing of coal, which rests upon precisely the same principles.

The ores that we usually have to deal with in Europe are those of lead, zinc, copper, and tin.

As is well known, they are nearly always met with and treated in the form of more or less argentiferous galena, blende or calamine, copper pyrites or copper glance, and lastly cassiterite. They are often mixed with other minerals, such as iron pyrites, or oxide of iron, mispickel, wolfram, &c.; whilst their veinstone contains one or more of such minerals as quartz, various forms of calcspar, dolomite, sulphate of barytes, fluor spar, &c., and pieces of the enclosing rocks (*country*) of the lode, such as sandstone, shale, grauwacke, granite, gneiss, &c.

This mixture, consisting sometimes of fine particles intimately blended together, sometimes, on the contrary, of coarse fragments, has to be broken up in order to separate the useful ores one from another, and to remove the waste.

The operations necessary for accomplishing this object, although complicated at first sight, are simple enough when they are viewed more closely.

They consist in breaking the stuff down to such a size that the pieces of the ore sought for, whether large or small, are set free, and contain the smallest proportion of waste or foreign ore allowed to pass by the smelting works, and in extracting these pieces immediately, so as to avoid the losses that would otherwise occur during their subsequent handling.

This process of separation will evidently increase in difficulty as the minerals are more intimately mixed together, since in this case the pieces will have to be made smaller.

It is easy to see, therefore, that the first process to which the produce is subjected, after being brought out of the mine, is a breaking up of the large lumps, followed by *picking*. After this the pieces that do not contain the ore in a sufficient state of purity can be rendered fit for smelting by having the barren veinstone hammered off—the operation called *cobbing*—or by being crushed and then subjected to processes for extracting as soon as possible all ore that can be separated in a saleable condition.

This separation cannot as a rule be properly effected by the machines in actual use unless the particles are approximately of a uniform size, and they must therefore in the first place be *classified according to size*.

(619) From what has been said it is evident that dressing, properly so-called, resolves itself into three principal processes, always preceded by a preliminary operation, consisting of picking out by hand—if necessary after breaking, washing, and cobbing—any pieces of ore fit to be smelted.

The three principal processes in dressing are as follows:

1. *Crushing the mixed stuff;* that is to say, stuff containing veinstuff or several kinds of ore.

2. *Classifying according to size* the cleaned or washed product of the preceding operation so as to facilitate the next process.

3. *Concentrating,* by jigging or washing, either by hand or mechanically, each size obtained by the classifying process. We

thus get a separation into *clean* ore, which is sent directly to the smelter, *waste*, which is thrown away, and *mixed* ore and waste (*dradge*) which is usually crushed again and passed through the same series of processes.

Theoretically therefore dressing is a very simple operation; its apparent complication is due to two causes. In the first place, the stuff is passed through the same processes over and over again, which naturally produces a certain amount of confusion in one's mind; and, secondly, the number of machines that have been invented and applied for dressing purposes is very great, though their extreme variety is not warranted either by the differences amongst the minerals that have to be treated, or by the diversity of the circumstances which occur in practice.

Thus, according to circumstances, *crushing* is done by means of rolls, stamps, or mills.

The *classification according to size* is effected by means of gratings, revolving screens, &c., and in the case of very fine particles by means of various kinds of apparatus known by the name of pointed boxes (*Spitzkasten*), or ascending current classifiers, which utilize the difference of velocity of fall in water of fragments of different sizes.

Lastly, the *separation* or *concentration*, independently of the hand-picking, either directly on arrival at the surface, or after cobbing. This separation is accomplished by numerous machines of every variety, upon which the imagination of engineers has long been busy. The principle of the whole of them is the same, as they are all founded on the effect of the difference of densities; that is to say, like the classifiers for the finer particles, they utilize the laws which regulate the fall of bodies in a fluid.

When viewed according to their general arrangement and mode of operation, these machines may be reduced to two principal types:

1. *Jiggers* of various kinds for gravel, and even for sands. These machines are coming into use for very much finer stuff than was treated by them formerly.

2. *Frames* or *kieves* of various kinds for fine sands and slime.

Such then is the general series of operations which we shall proceed to examine in detail.

Preliminary operation—Picking, spalling, and cobbing of the lumps. Cleansing of the smalls.

(620) The preparation of the ore before it is sent to tne various dressing machines may be divided into three distinct parts:

(1) *Breaking and picking in the working-place*; (2) *Breaking at the surface* (*ragging and spalling*); (3) *Cobbing.*

Underground breaking and picking.—The work of picking in the working-place is carried out with all the care and all the precautions pointed out in No. 374, where attention was called to the great importance of this operation. This importance, as will be remembered, arises from the fact, that every particle of valuable mineral not loaded and sent to the surface is irremediably lost, although the greater part of the expense of extracting it has been already incurred, and it has no more charges to bear than those connected with haulage and winding; and that, on the other hand, it is useless to incur the cost of bringing to the surface a certain amount of rubbish that might be usefully employed for stowing. It has been shown however that, when these two faults are compared with each other, the second one is less grave than the first, and that it is *better to bring some deads to the surface than to lose useful mineral.*

The amount of care that should be bestowed upon this operation evidently depends upon the greater or less difficulty it presents, as well as upon the richness of the ore. But in every case the picking should be done by careful, intelligent, and practised workmen, who will always collect the smalls with the greatest care, since they are often richer than the lumps (*rocks*), the useful ore being usually more friable than its veinstuff.

Picking underground is carried on with difficulty, in consequence of the uncertain light afforded by a miner's lamp; and there is no harm in doing it in a rough and ready fashion, unless there is too little stuff for stowing, or the underground haulage is difficult and costly. Moreover, it can be easily completed at the surface under more favourable conditions as regards light, and with a less expensive form of labour than that of the miners employed in getting the ore. The principles of this operation will therefore be:

1. Not to push the breaking and picking too far, and to reject nothing but what is decidedly waste; the muddy smalls, of which one cannot be sure, should always be brought to the surface.

2. To leave the lumps unbroken, so long as they can be easily handled and carried to the nearest *shoot*, as they can be more easily examined at the surface.

For this work heavy sledge-hammers are employed weighing 13 to 22 and even 26 pounds (6 to 10 and even 12 kil.), and having handles 27½ inches (0·70 in.) long; and it is often useful to employ iron wedges in conjunction with these sledges for splitting the ore up more conveniently, especially when it possesses a slaty structure, which is frequently the case.

(621) The product of this operation is exceedingly variable, and is generally classified according to its size, quality, and richness. (This was the case in former days, at all events; but the increasing cost of labour tends to make mining engineers give up these divisions.)

The deads being put aside and employed as stowing, as we have already said, the ore-bearing part may be divided:

1. According to its size, into lumps (*rocks*) and smalls, which are loaded and sent to the surface separately. This division is made in the greater number of cases, as it gives the considerable advantage, from an economic point of view, which arises from treating the mineral in the first state.

2. As regards its quality, into different kinds, which vary more or less according to the nature of the ore and its veinstuff, according to the more or less intimate nature of their mixture, and even according to the structure of the lode, which sometimes renders this separation very easy even inside the mine.

Thus, for example, in a lode with the ore disseminated through it in large lumps, we might, if necessary, separate the pieces consisting mainly of blende from those consisting mainly of galena, the lumps with a barytic veinstuff from those with calcspar, &c., because all these differences are important, as far as the mechanical treatment is concerned. But in general it may be said that such careful picking would be trenching upon the next

operation, and can be done much better at the surface, save under exceptional circumstances.

3. Lastly, according to richness, we may separate rich, medium, and poor lumps (*rocks*); and it is as well to mention that in special cases the ores of the precious minerals, such as ruby-silver ore, and native silver, may have to be put aside immediately, and be taken to the surface in closed boxes, sacks, &c.

Whatever may be the limit to which the operations we have described are pushed, the various products will be delivered as follows:

The large blocks (*rocks*) to the *spalling-floors.*

The *smalls* to the sizing machinery; for, as we have already seen, sizing is the second of the complete series of operations. As to the exceptionally rich pieces, if there are any, they will be sent to the smelting works, either directly or after being stamped dry, in order to distribute their yield uniformly.

It is easy to see that the preceding principles cannot always be rigidly adhered to. The breaking and picking underground should be done more or less thoroughly according to the price of labour and the nature of the ore, whence it results that the kinds of the picked ore vary according to circumstances. It may even be expedient not to undertake any kind of sorting underground at all, except the separation of the undoubtedly dead stuff, although this is not a system to be recommended generally. But in this case the *spalling* and picking at the surface, which are of the same nature as the breaking and picking in the working place, should correct their shortcomings, and should receive more supervision to make up for what was wanting underground. Hence we see that the two operations are very similar, and can to some extent be supplementary to each other.

(622) If, as sometimes happens, the rocks and the smalls are brought to the surface mixed together, the first necessary operation is to separate them. This is effected to a certain extent when the waggons are tipped at the surface, for the large pieces roll away to the bottom of the pile, while the smalls remain near the top. We can in this way pick out the pieces that are larger than the

fist for instance. It is usual however to employ other modes of separation which are more perfect, and cost less for labour.

The waggons may be tipped at the upper end of an inclined screen, which lets the small pass through between the bars whilst the large is retained. This is the usual process in the case of coal. Or the stuff can be thrown on to a fine grating, either fixed or shaking, according as the ore is more or less clean, because a shaking grating causes the particles to clean themselves to a certain extent by their mutual friction.

Lastly, if this method of cleaning is insufficient, it becomes necessary to direct a more or less strong jet of water on to the ore according to the stickiness of the mud which covers it, and it may even be necessary to subject the ore to a washing or cleansing process similar to that which will be described further on when we speak of the treatment of the smalls.

(623) Whatever may be the actual process employed, the large stones (*rocks*) arrive at the *spalling floors*, which ought to be as near the mouth of the mine as possible, so as to avoid the carriage of useless deads. The floor ought to be composed either of firmly-beaten earth, or should be paved with stones, with the view of avoiding the loss of fine stuff which would inevitably happen if this precaution were neglected.

The tool made use of for this operation is an iron sledge faced with steel, about 6 in. ($0^{\cdot m}15$) long, weighing from 3 to 5 pounds (1½ to 2 kil.), and having an ash or hazel handle about 3 ft. 6 in. ($1^{\cdot m}10$) long. (Figure 480.)

The large stones can thus be thoroughly broken up; but sometimes the stuff is not considered to be broken finely enough in this way, and it is then subjected to a second process of breaking by means of a much lighter hammer, made of cast-steel, weighing about 1 pound (0·5 kil.), and having a long flexible handle about 2 ft. 4 in. ($0^{\cdot m}70$) long.

The object of this operation is to obtain pieces of ore small enough either for the picking and cobbing, or for going at once to the crushing rolls. The size therefore should not exceed 3 to 4 inches (8 to 10 centimetres). This process has, however, the

defect of being both very costly and of producing a large quantity of smalls; and for these reasons it has been almost entirely replaced during the last few years by mechanical breakage, effected by means of the *American stone-breaker*, or the *stone-breaker with jaws*.

This machine, which receives its name from the fact that it works somewhat like the human jaw, consists (fig. 481) of a fixed jaw, which may be either vertical or inclined at a certain angle, and of a movable jaw, which receives its motion from an eccentric, and is alternately brought nearer to and withdrawn from the former.

The stones which fall into the opening are caught between the two jaws, and at each stroke of the movable one they are powerfully squeezed, and finally reduced to such a size that they can drop through the lower opening. The width of the latter can be regulated by means of a wedge worked by a bolt and nut.

A suitably-arranged spring draws back the movable jaw after each stroke, and a heavy fly-wheel serves the purpose of storing up the energy of the motor during the entire revolution, notwithstanding that the resistance is intermittent. Lastly a screen, fixed or shaking, with its bars $\frac{3}{4}$ to 1 inch (20 to 25 millimetres) apart,* receives the broken stuff, and immediately separates it into coarse and fine.

As this machine is very simple, easily kept in repair, and very convenient, it has come rapidly into use, and it may be said that it is now difficult to visit any dressing-floors without meeting with it.

It can break rapidly, and with a small amount of attendance, lumps of from 10 to 15 inches ($0^{\cdot m}25$ to $0^{\cdot m}40$) across, and bring them down to a very small size, with a maximum dimension of $\frac{3}{4}$ or even only $\frac{3}{8}$ inch (20 or 10 millimetres).

The amount of work done will naturally depend on the dimensions of the stuff treated, the nature of the ore, and the speed at which the machine is driven. Thus a medium-sized stone-breaker, which requires a force of 3-horse-power, and works at the rate of 60 revolutions per minute, will break about 30 tons of ore per day.

* Revolving cylindrical screens are also used.—*Translators.*

A larger and stronger machine, working at the rate of 150 revolutions per minute, would break 70 or 80 tons, and would require 12-horse-power.

A machine of this kind, with parts proportioned to the work required of them, and made wholly of cast-iron* of exceptional strength, occupies but little space, effects a great economy of labour, and executes a given amount of work much more rapidly than it could be done by hand; and a further point worthy of particular notice is the fact that it produces less dust than other modes of breaking.

(624) Whatever may be the manner in which the breaking is performed, it produces in addition to the fine stuff, which should be mixed with the *smalls* coming directly from the mine, lumps of an average size of 3 to 4 or 6 inches (8 to 10 or 15 centimetres); but they will vary more or less in quality according to the physical and chemical nature of the lode.

These varieties are:

1. Ore fit for smelting. As many varieties should be sorted out as there are metals in the lode. We should thus have solid lumps (*prills*, Cornwall) of galena, of blende, of copper pyrites, &c., and each of these lumps may also contain a certain quantity of foreign metal or of veinstuff, the maximum amount of impurity allowed being dependent on the exigencies of the metallurgical treatment.

2. Stuff containing large pieces of ore, which has to be *cobbed*. In this operation the lumps are broken still smaller by means of hammers, and the pieces fit for smelting can be picked out as in the previous case.

There will be further an opportunity of at once separating the broken pieces, if it can be done easily, into several classes, according to the nature of the ore and of the veinstuff; but the extra cost of labour must always be borne in mind.

Thus, independently of the pieces consisting mainly of galena, blende, or copper pyrites, etc., a further separation may be made, if

* In some of the rock-breakers made now-a-days wrought-iron tie-rods are used for taking the strain due to crushing, and the wearing parts of the jaws are made of steel.—*Translators.*

thought advisable, according to the nature of the veinstuff, when the various minerals composing the lode present sufficiently marked differences of specific gravity. For example, we may pick out and set apart the pieces with calcspar as veinstone, others with barytes as veinstone, &c.

This separation would be without any advantage as far as the pieces ready for smelting are concerned, but it is very useful in this case, because it should lead to a difference of treatment in the subsequent dressing process.

3. Stuff to be either crushed or stamped, according to the size of the particles of ore, but possessing this general character, that the different varieties of minerals are too intimately mixed up to make it possible to separate them conveniently by cobbing.

In this case also several classes might be made according to richness, or according to the nature of the veinstuff with reference to the subsequent mechanical treatment; but here the separation would be of less importance, and less easily carried out, than in the previous cases.

If it is decided to undertake this operation, which is not commonly done, it will require to be very closely looked after; for though it can be carried out with the lumps intended to be cobbed, the subsequent crushing in this case causes the various qualities to be mixed up, and distinction becomes thenceforward impossible.

4. Lastly, the waste or deads, which have no value.

This class should be watched carefully, since any ore it may contain is lost absolutely. It is necessary to take into account a whole crowd of considerations, such as the price of labour, the value of the metal, the difficulties of separation, the cost of smelting, &c. In a general manner, however, it may be said that the waste should be very poor, because it will be worth while treating it if it merely contains enough ore to pay the dressing cost, without taking into account the expense of the mining proper.

(**625**) The operation of cobbing and picking consists in separating the ore by hand, with the aid of the hammer, into various classes, similar to those described above.

It differs from the two preceding operations in this respect, that the method of breaking is intentional. The cobber, working in a comfortable position, can direct the blow of the hammer as he pleases. For example, he can knock off a small piece of blende from a lump of nearly pure galena, and so render the small piece or the other fit for smelting. He can chip a morsel of veinstone from a lump of ore, &c.; and he does everything in such a way as to be most advantageous for the future treatment. In the two preceding operations, on the other hand, the picking took place after the ore had been broken up at random.

This work of cobbing and picking is of much importance in dressing operations. It can be pushed more or less far according to the nature of the ore and its state of dissemination in the lode; and the engineer himself must be the judge of where it is best to stop it in the case of any given vein. But it may be said in a general way that it is well to push it as far as possible, as the increase of cost for hand labour, which results from doing so, will be largely compensated by avoiding the losses which the same ores would incur in passing through the processes of crushing and washing.

This operation, as we see, is the complement of the preceding one. As in that case, and here even in a higher degree, any mistake in classification is irreparable. It may be that a piece of ore is thrown away whose yield of metal is sufficient to cover the cost of treatment, or that ore of one kind is thrown by mistake into heaps of a different kind, and is consequently subjected to a treatment that does not suit it and gives rise to considerable losses.

(626) Products from several quarters come together in the house or shed devoted to the operation of cobbing and picking. In the first place stuff may be sent thither directly just as it arrives at the surface, if the underground picking has been carried far enough. Some also may have been picked from the stuff after spalling or breaking with the American stone-breaker.

These two operations produce, as we have seen, fragments of ore of a sufficiently uniform size, which have been picked according to

their nature, in such a way as to avoid too much complication, and too great an effort of attention on the part of the workman; so that he will generally have to make one principal product, and several secondary ones.

The work, which requires a quick eye and little strength, may be conveniently done by women, or, better still, by children, unless indeed it is reserved as a means of giving employment to old workmen who are incapable of performing any harder labour.

The last method has always the disadvantage of confiding a comparatively delicate task to men whose sight is sometimes no longer good.

The tool employed in this work is a small hammer (fig. 482), the weight of which should not exceed 2¼ to 2¾ lbs. (1 to 1·2 kils.), having a short handle and one face square, and the other drawn out to a cutting edge, perpendicular to the axis of the handle.

For certain special ores other forms may be used with advantage.

Thus the shaly ore of Mansfeld is split up by means of a hammer with two cutting edges parallel to the handle; whilst for the concretionary calamine of Silesia the tool has a square face at one end, and the other drawn out to a point.

Sometimes the operation is still further completed by using a little scraper for detaching the last particles of rich ore adhering to lumps of veinstuff, or *vice versâ*.

(627) The operation is therefore a very simple one; but, as we have already said, it is one of much importance, and consequently it is advisable to place the workpeople in such conditions that they have a minimum amount of fatigue, and can consequently apply their whole attention to it.

The working place should be covered, well lighted, and capable of being heated in winter, at least in the colder climates. The floor should consist either of beaten clay, boards, or paving-stones.

The workpeople should be seated on benches or stools, and not on the ground, as that would tire them more. The tables on which the cobbing is done should be placed opposite to the windows, unless the room is lighted from the top, and a tap should be fixed above each of them for watering the stuff, so as

to prevent the production of unhealthy dust that might be raised during the operation.

The work consists in taking the pieces one by one in the left hand, and breaking them with the hammer, held in the right hand; in detaching, if necessary, by means of the scraper any well-defined particles of foreign ore or of veinstone that can be so separated; and lastly, in distributing the various products into as many baskets or boxes as there are different classes picked out.

This work should be *constantly* under the supervision of a skilful foreman, whose business it is to prevent pieces that are too rich from being thrown away, and also to prevent too large a proportion of veinstuff or of foreign ores from being put with the ore ready for smelting: the products will be of a similar kind to those obtained in the preceding operation, but they will be classed if possible with a greater amount of care.

(628) The success of the treatment will depend on the care and intelligence with which the three last operations are conducted. They may supplement each other to some extent at different stages, but the final result is the same.

We shall once more repeat that this result consists in:

1. Withdrawing everything that can be withdrawn from the losses inherent to dressing properly so called, and this at the cost of a somewhat expensive kind of labour; but it is expedient not to push this principle too far. The amount of the losses referred to is almost unknown, because they occur in all the operations without exception, and because the escaping ore is hidden in a large body of water or of sterile matter. They are large in every case, and may be estimated at 20, 30, and even 40 per cent. of the ore.*

2. Dividing the remaining portion into as many classes as are necessary in order to simplify the succeeding operations, and make the treatment easier and somewhat *shorter*, so as to avoid losses, not entirely it is true, but to a great extent, and as far as is practically possible.

* The loss in dressing tin ore at Cornish mines is estimated by Mr. Frecheville to be only 11 per cent. *Eng. and Mining Journal*, vol. xl. (1885) p. 416.—*Translators.*

The engineer who has to study the best method of carrying on the process of cobbing and picking should therefore examine the more or less complicated character of the ore he has to deal with, and, in deciding upon the exact course to be pursued, base his treatment, not only on the expense of labour, which depends upon the greater or less complexity of the lode, but also upon the requirements of the smelting works and the metallurgical treatment.

It is evident indeed, as regards this last point, that the difficulties of mechanical preparation will decrease with the progress of metallurgy, and that when the day arrives in which two metals like lead and zinc can be extracted practically and economically from a mixture of blende and galena associated with any kind of veinstuff, the greater number of dressing-floors on the Continent will disappear, as there will no longer be any reason for their existence.

(629) The smalls coming from the mine, generally mixed with a certain quantity of the clay so often contained in mineral veins, and nearly always containing a number of large lumps which can best be treated along with the *rocks*, are usually subjected in the first place to a preliminary washing.

This consists in passing them over screens under a stream of water, together with the smalls produced during the operation of spalling, and the poor smalls coming from the cobbing-shed. The bars of the screens are usually 1, 1¼, or 1½ inch apart (30, 35, or 40 millimetres).

The large stones caught by the bars are washed clean and then treated like the rocks. The finer parts which traverse the screen are then cleaned by means of different kinds of machines, of which there were formerly a large variety. These machines may be divided into three separate categories, thus:

1. Stationary appliances.
2. Moving machines.
3. Trommels, or revolving screens.

(630) The *stationary appliances* consist either of washing-pits or fixed gratings. The washing-pits have a paved bottom, slightly

inclined, 10, 16, and even 23 feet long (3, 5, and even 7 metres), they are 5 to 10 feet ($1^{\cdot m}5$ to 3 metres) wide, with wooden sides 15 to 20 inches (40 to 50 centimetres) deep. A strong stream of water is sent down them, and the labourers shovel the ore from one side to the other three or four times before it arrives at the upper end.

This contrivance is principally employed for washing iron ores, and in general for any clayey ore. On an average about 25 tons per day can be treated in one of these pits; but the stuff is not very well cleaned, and a considerable amount of labour is required.

The fixed gratings which have been already mentioned scarcely require any further description; they are simply gratings watered by means of one or more jets of water. Sometimes several of them are put one above the other, so as to effect a preliminary sizing.

(631) The *moving machines* are either hand sieves or shaking screens.

The sieve, or riddle, is moved up and down vertically in water, either directly by hand or by means of a flexible beam, which is made to oscillate.

The shaking screen consists of a strong frame of cast-iron, or wood lined with sheet-iron, slightly inclined, provided with one or with several gratings, if sizing is to be carried on at the same time, and it receives a rapid succession of horizontal shakes by any kind of mechanical arrangement, while at the same time a strong stream of water is made to play upon the ore.

The principle of these machines is the same as that of the preceding ones, but they have the disadvantage of being very heavy, and of acting somewhat imperfectly when the ore is decidedly clayey.

(632) We shall not dwell upon these appliances, because they have been all but completely driven out of use by other much lighter and handier machines, which also do better work, namely, the *washing drums*, or *trommels*, as they are often called.

A trommel is a barrel in the form of a cylinder or of a truncated cone, horizontal or slightly inclined, turning round its own axis.

It is the machine employed for similar purposes in most other industries; the only wonder is that so long a time elapsed before it was adopted in dressing ores, for it furnishes the best possible means not only of cleaning the ore, but also of sizing it, as we shall see further on.

The rotation of the trommel produces the same effect as the shakes in the preceding case. But here we have a more compact machine, a simpler mode of working, and the equivalent of a longer screen, which is consequently more effective.

In most cases a washing-trommel consists of a cylinder of strong sheet-iron, about ½ inch (11 to 12 millimetres) thick, of a length depending on the greater or less difficulty attending the work of cleaning, and varying between 5 and 10 feet ($1^{\cdot m}5$ to 3 metres). If the ore is very clayey, the trommel is sometimes armed with spikes in its interior, which break up the lumps of clay, and help to disintegrate them in such a manner that they may be finally swept away by the water that is always flowing copiously through the apparatus.

This arrangement is usually sufficient, but for more difficult cases more effective machines are available.

One of the best is known as the Corphalie trommel.

It consists of two truncated cones joined by their bases (fig. 483). The first, having a very narrow opening, receives the ore from a hopper together with a plentiful supply of water, whilst the second cleans it by means of spikes riveted to the sheet-iron inside.

The level of the lower edge of the opening through which the ore enters being higher than that of the opening through which it is discharged, it is easy to understand that the washed ore is obliged to flow out under the pressure of the stuff behind it, in spite of having to travel uphill from the lowest point of the drum.

The same result might be obtained if we fixed sheet-iron plates round the inside in the form of a helix, which would work like an Archimedean screw; but the washing would not then be so thorough as with the spikes, and the employment of both together, although no doubt an excellent plan, would perhaps complicate the machine and weaken its structure through the multiplicity of

joints that would have to be made. This defect could not well be obviated except by making the drum longer, and so spreading the spiral blade and the spikes over a greater area.

When the stuff is discharged, the clayey mud and the finer particles pass through the holes of a perforated sheet-iron screen, which are not more than $\frac{1}{8}$ inch (3 millimetres) in diameter. The remainder passes on to a coarser screen, with the bars about $\frac{1}{2}$ inch (13 millimetres) apart. The stuff too coarse to pass between them is picked by hand, and the rest is sent to the sizing-trommel, which we shall describe further on.

This process of sorting by hand, without any breaking with a hammer or other accessory operation, is a very important one, and cannot be carried too far. It is, as it were, an intermediate process between *cobbing* and concentration properly so called, as the former operation can be carried out only with lumps that are large enough to be broken with advantage, whilst the latter is of little use until the stuff has been reduced to a comparatively small size.

The operation is a very simple one, and is performed as a rule by women or children on any kind of flat table. A very convenient arrangement in common use is that of a round sheet-iron table turning on a vertical axis. The pieces that do not pass through the screen fall on to the revolving table, and are spread out by means of a scraper.

Boys placed round the table can easily do the picking, and not only select the richer from the poorer ore, but also sort it into the various qualities, as already explained.

(633) We see that even for comparatively difficult cases of washing, the revolving drums or trommels are very simple machines. Their use has become very extensive, more especially that of cylindrical drums or truncated cones, and these are preferred to hexagonal ones, which do not produce any better results, and are more difficult and costly to keep in repair.

A trommel of ordinary size is about 5ft to 6½ft. ($1^{m}50$ to 2 metres) long, 3ft. 4in. to 5ft. (1 metre to $1^{m}50$) in diameter, and makes 8, 10, or 12 revolutions per minute. The quantity of stuff passing through it will naturally vary greatly according to the quantity of

water flowing into it, and, above all, according to its inclination if it is cylindrical, or according to the difference of level of its two ends if it is a truncated cone. This is an element whose best value must be found by experiment according to the nature of the material that is being treated.

With an average ore, 25, 30, or 35 tons may be passed through it per day, with a consumption of water amounting to 1300, 1700, or 2200 gallons (6, 8, or 10 cubic metres) according to circumstances.

The power required is small; two or three horse-power will generally be sufficient.

(**634**) Although trommels are no doubt the best machines for removing clay from ore, and can be applied to every kind of stuff, there is another well-known contrivance which we feel constrained to describe, and which is still commonly employed in washing iron ores. We refer to the mechanical washing trough (in French *patouillet*).

This is a semi-cylindrical trough, with an axle provided with arms placed along its axis. When the axle revolves the arms stir up the ore, rub off the clayey particles, dilute them with the water, which carries them away immediately, and pass the clean lumps onwards to the end of the trough, where they are discharged.

The size of an apparatus of this kind will vary according to circumstances. Figure 484 represents a large one that was erected under the most favourable conditions; but it is very rarely the case that machines of this kind are constructed so well as this one.*

It consists of a trough 14 feet 9 inches ($4^{\cdot m}50$) long, lined inside with planks covered with cast-iron plates, and closed at the ends by semicircular iron plates, one of which has an opening at its bottom for allowing the ore to pass out into the pit in which a dipping-wheel is working.

The ore is stirred up, and at the same time pushed towards the end of the trough by longitudinal bars, which are placed obliquely to the generatrices of the cylinder, and fixed to the shaft in the

* See *Annales des Mines*, viie série, tome viii., 1875.

ordinary manner by means of bosses and radial arms. When it arrives at the end it is lifted by the dipping wheel to the level of the floor, where it can be stored.

A machine of this kind is capable of washing 35 to 40 tons of ore in a day of ten hours. A well-arranged trommel might be advantageously substituted for it, both as regards economy of power and perfection of washing.

CHAPTER XXIV.

DESCRIPTION OF THE SUCCESSIVE OPERATIONS OF DRESSING.

§ 1. Crushing.

(635) The object of crushing is to reduce the stuff to a smaller size; pieces of all dimensions, from the largest to the smallest, have to be treated, such as lumps from the cobbing-house, mine-smalls, or *dradge* (pieces of mixed ore and veinstone) produced by some of the dressing processes.

The crushed product consists in part of homogeneous grains containing only one mineral species—either ore or waste—which can be immediately extracted, either to be sent directly to the smelting works, or to be thrown away, and in part of particles of *dradge* which have to be crushed finer.

Although it is true theoretically that the stuff might at the first operation be reduced to the degree of fineness requisite for at once separating the different products completely, we must add that we should be quickly stopped on this path, not only by the additional cost which would result from this method of procedure, but also by the greater losses which would ensue in the subsequent treatment, and which would increase rapidly with the fineness of the crushing.

The general principles, which should invariably be followed in practice, are, firstly, never to carry the crushing further than the degree of fineness strictly necessary; secondly, to separate as soon as possible the rich part capable of being removed, so as to prevent its being subjected to loss in the subsequent treatment; and, thirdly, to get rid of the waste with all possible despatch, so as not to burden the dressing with any unnecessary cost in washing it.

(636) Many machines have been tried and employed for crushing; but the principal types in use, independently of the stone-breaker, which has been described above and the object of which is a little different, are reduced to three. They are:

1. Rolls.
2. Stamps.
3. Mills.

Although, for various reasons, it is difficult to express a clear, precise, and incontestable opinion upon the comparative merits of these machines for crushing purposes, we believe, however, we may say that:

1. Rolls are fit for treating stuff from about 3 or 4 inches in diameter downwards, and reducing it to a very much smaller size. They produce less *dust* than the other crushing machines; but, at all events at the present time, they are not adapted to the crushing of fine sand, which has never been successfully treated by them.

2. Stamps applied to the treatment of similar stuff usually crush it more unevenly, and make more dust; but they will crush all sizes down to the very finest, and will reduce them to a very extreme state of division.

3. Lastly, mills are *par excellence* the machines for producing the greatest quantity of impalpable powder; a result which should as a rule be avoided, as is well known, on account of the considerable losses which occur afterwards in dressing. But it is advisable, on the contrary, to employ them in certain special cases when this extreme fineness is required, particularly in the cases when subsequent metallurgical operations, such as roasting or amalgamation, render it necessary.*

(637) Leaving aside mills, the object of which is evidently special, and the employment of which should be strictly limited to the cases we have just pointed out, we may make the following remarks upon the first two classes of machines. The work of rolls may be easily *regulated* by the distance apart at which they are set, whilst that of stamps is to some extent ruder, as the means

* Extreme fineness before roasting may be both unnecessary and undesirable. T. Egleston, "Rolls for Crushing Ore," *Engineering*, vol. xl. 1885, p. 464.—*Translators.*

available for bringing the stuff to a desired state of fineness, and not beyond it, are far less under control. Rolls require no water, whilst stamps require *a great deal.* Lastly, they take up little room, and make no noise, whilst stamps are cumbrous, and deafen the workmen, which is both inconvenient and troublesome.

On the other hand, we must add, that as stamps will crush finer, and as their mode of action is very different from that of rolls, which act by pressure whereas stamps act by blows, it will be advisable to employ the latter whenever it is necessary to crush hard stuff with the ore finely disseminated through it.* As nearly all lodes contain some parts in which the ore is thus finely distributed through it, there is generally in all dressing establishments a residue of *dradge* unfit for crushing by rolls, and which therefore has to be stamped. On this account it is difficult to find any tolerably complete dressing-floors which do not possess a few heads of stamps. We must add that the use of stamps will also be advisable when the *dradge* contains one substance which is decidedly harder than the others associated with it; for by properly calculating the weight and the drop of the stamp-head, we can crush the soft part, and preserve the hard part more or less intact, and its separation is thus rendered very much easier.

This principle may, for instance, be applied to a mixture of pyrites, blende, and galena, as the two last are crushed pretty easily, whilst the first remains in the form of more or less rounded grains: the pyrites may be afterwards separated by a mere process of sizing, which is a very great advantage.

Similarly, in the case of a simple hard ore associated with a soft veinstone, a separation may be effected at once by the same process. In fine, it may be said that each of the above machines has its

* This dictum can no longer be accepted universally. *See* C. A. Stetefeldt, "On the Progress which has been made in the Construction of Dry-crushing Silver Mills," *Report of the Director of the Mint upon the Production of the Precious Metals in the United States during the calendar year* 1883, p. 738; Washington, 1884. S. R. Krom, "Improvements in Ore-crushing Machinery," *Eng. and Mining Jour.*, vol. xl. p. 25; New York, 1885. T. Egleston, "Rolls for Crushing Ore," *Engineering*, vol. xl. p. 464; London, 1885. These papers show that for the fine crushing of silver ores previous to lixiviation rolls are far cheaper and more effective than stamps. Not only is the first cost much less, but there is great economy in the working expenses. The articles referred to deserve the special attention of all miners who are now using stamps.—*Translators.*

special well-defined object, and that when it is a question of crushing a given substance to a given degree of fineness, there is usually no difficulty in deciding which is the best for the purpose.

(638) *Rolls* are either plain or fluted.

Fluted rolls were principally employed formerly to do the work of the stone-breaker; they are nearly everywhere abandoned nowadays.

Plain rolls, which are in general use, are employed for stuff which has already passed through the stone-breaker, and is already much reduced in size.

The complete machine consists of the following parts (fig. 485):

1. A pair of rolls, consisting generally of cast-iron cores or hubs, firmly fixed upon strong shafts, with shells or tires of cast-iron or steel, and placed a small distance apart. Whilst one receives the movement of the motor directly, the other is simply drawn round by the adhesion of the ore caught and crushed between the two rolls. In this way, not only is there nothing to fear from any breakage of the gearing,* which was of frequent occurrence when the two rolls were connected in this way, but also the wear is spread more evenly over the surface of the rolls, as the parts opposite to each other vary continually on account of the relative sliding which takes place.

2. Springs,* more or less powerful according to the hardness of the substance to be treated, which press upon the plummer-blocks of one of the shafts. They are intended not only for pressing the two rolls one against the other with a definite degree of force, but also for allowing them to move asunder a little, which is sometimes rendered necessary by the exceptional toughness of a fragment of veinstone, or by some hard body accidentally happening to fall between them.

The shells for coarse crushing are generally of hard or chilled cast-iron, so as to offer a greater resistance, and crush the ore better; but as they wear somewhat rapidly, inequalities are produced which, though without any great inconvenience for coarse crushing, would unfit them for the fine; consequently for fine crushing cast steel shells must be adopted, and then as soon as they are worn they

* Krom drives his rolls with *belts*, and has no springs. Stetefeldt, Krom, and Egleston, *Op. cit.—Translators.*

can be put into the lathe and turned up afresh.* The tire, whether of cast-iron or steel, may be made conical inside, so as to allow it to be drawn tightly on to the core by bolts; this is the simplest and strongest method of fixing it on.

Springs of various kinds may be used. The old fashion was to have weights acting upon a lever, and these may still be seen. They have the disadvantage of bringing back the movable roll with too sudden a shock.

The springs principally in use at the present day are either india-rubber ones, as shown in figure 485, or the Belleville springs, which precisely resemble those sometimes employed for buffers of railway trucks. The minimum width of opening between the two rolls is regulated by a block of cast-iron placed between the plummer-blocks of the two axles.

(639) One of the principal points to be decided when rolls have to be used is their diameter, which varies with the size of the stuff to be treated.

We will suppose two rolls of equal diameter (fig. 486) to be turning in the directions shown by the arrows, their distance apart being 2 s. In order that the lump with the radius r may be seized and carried on by the revolving roll, it is necessary that the vertical component of the friction which tends to produce this effect, augmented for greater accuracy by the weight of the lump, should be greater than the vertical component directed upwards of the normal reaction of the lump against the rolls.

Calling this normal pressure N, and consequently fN being the friction, we get:

$$2f\mathrm{N}\cos\alpha + \mathrm{P} \geqq 2\mathrm{N}\sin\alpha.$$

But as the weight of the lump is very small compared with the pressure caused by the rolls, we may say simply:

$$2f\mathrm{N}\cos\alpha \geqq 2\mathrm{N}\sin\alpha,$$

or

$$\tan\alpha \leqq f.$$

An examination of the figure at once gives the equation

$$\cos\alpha = \frac{\mathrm{R}+s}{\mathrm{R}+r};$$

* Chilled iron rolls may be turned by an ordinary tool if the motion is sufficiently slow. E. D. Peters, "Modern American Methods of Copper Smelting," *Eng. and Mining Jour.* vol. xl. p. 60. New York, 1885.—*Translators.*

and we now deduce $\tan \alpha = \frac{\sqrt{(R+r)^2 - (R+s)^2}}{R+s}.$

The limit is therefore:

$$\frac{(R+r)^2 - (R+s)^2}{(R+s)^2} = f^2;$$

and consecutively $\quad R + r = (R+s)\sqrt{1+f^2},$

or $\quad r - s\sqrt{1-f^2} = R\,(\sqrt{1+f^2} - 1).$

As the size of the lumps to be fed in is known approximately, and as the maximum size which they must not exceed after crushing is fixed beforehand, s may be expressed as a function of r.

Therefore, putting $s = \mu r$, it becomes

$$R = \frac{r\,(1 - \mu\sqrt{1+f^2})}{\sqrt{1+f^2} - 1},$$

or nearly $\quad \frac{R}{r} = \frac{2\,(1-\mu)}{f^2}.$

If, for example, we take $\quad \mu = \frac{1}{2},$

$f = \frac{1}{3},$

we obtain $\quad R = 9r.$

We see that the smaller the diameter of the rolls, the smaller will be the pieces that can pass through. This remark is of interest in a large number of industries besides that of ore-dressing.

It is found in practice that the diameter of rolls for coarse crushing rarely exceeds 2 ft. 4 in. to 2 ft. 6 in. (70 to 75 centimetres); but it should be very much less for fine stuff. The length generally varies but little in practice, and is rarely more than 1 ft., or 1 ft. 4 in. (30 to 40 centimetres).

A complete establishment is usually provided with two or three pairs of rolls for treating stuff of all sizes; and we may reckon that each pair of rolls will require 3 to 6 horse-power, according to the kind of stuff they have to treat.

(640) After the machine has been erected, it will be found that its proper working depends upon two principal points, viz.:

1. Regularity of feed, which should be as perfect as possible, so that the rolls may not be revolving empty at one moment and immediately after be so full as to be choked and even stopped.

Regularity is attained by employing a steady workman for running down the stuff properly from the charging hopper, or in the case of comparatively fine stuff by an automatic apparatus, such as a bucket elevator, screw feeder, &c.

2. Speed of rotation, which should decrease as the hardness of the ore increases, and should err on the side of slowness rather than be too great, as in the latter case the pieces dance about on the rolls.

Thus the result of some interesting experiments made by the Vieille Montagne Company showed that a pair of large rolls 2 ft. 5 in. (74 centimetres) in diameter, treating very hard ore, crushed only 15 tons per day when making 26* revolutions per minute; whereas they crushed more than 25 tons when the speed was reduced to 9 revolutions per minute.

A pair of rolls for fine stuff, working under similar conditions and upon the same kind of ore, crushed 9 tons and 20 tons respectively. It is evident therefore that it will be useful to ascertain by actual experiments what speed is most advantageous for crushing any given class of ore.

Rolls will crush stuff varying in dimensions from 2, 2½, or even 3 inches (5, 6, or 8 centimetres) to a very small size, but not below $\frac{1}{25}$ inch (1 mm.). The largest rolls are used for crushing ore as it comes from the mine, which is too poor to be picked by hand; and the medium and fine rolls for the mixed ore and veinstone (*dradge*) obtained in the subsequent processes of classification and concentration.

(**641**) *Stamps* have been employed from very early times for crushing ore, and although they have been partly superseded by rolls, we have just pointed out that the objects and functions of the two kinds of machines are not identical, and that both may be used at the same time. A battery of stamps is composed essentially of the following parts:

1. A *frame-work* for guiding the lifters, so as to ensure a proper transmission of the force that works them, and resist the reaction of the blows caused by the fall of the stamps.

* Krom drives his rolls at a speed of 80 to 100 revolutions a minute. Stetefeldt, Krom, and Egleston. *Op. cit.—Translators.*

2. The *stamps*, varying in number from 4 to 6 or 8. They are lifted up one after the other by cams suitably arranged upon a shaft, and they crush the ore by the force of their fall.

3. The *kofers*, *mortars*, or *battery-boxes*. These are partially closed boxes, which receive the stuff and retain it until it has been reduced to the state of fineness desired.

The details of the arrangements of stamps have undergone an infinity of modifications according to the nature of the ore, the degree of fineness required, and especially according to the country in which they are used. It would be difficult to enumerate all these modifications in a general description; but we can at least point out the principal ones, and explain their advantages and defects.

(642) The frame-work of stamps consisted formerly of strong beams rendered sufficiently firm by lateral stays, and connected together by suitably-arranged cross-timbers. Each of these cross-timbers was in its turn joined to the one in front of it by means of wooden pins, which thus formed guides for the lifters about 3 or 4 feet above the *kofer*, and also near the top.

Each stamp consisted of a *lifter*, or *stem*, made of pine, beech, or oak, provided at the bottom with a *head* of hard cast-iron, generally chilled; the head and the lifter were of about the same section, 5½ to 8 inches ($0^{\cdot m}14$ to $0^{\cdot m}20$) square, and the head was attached to the lifter by a shank fixed in with wedges, the end of the lifter being prevented from splitting by iron rings. The height of the head, which gradually diminished with the wear, was from 8 to 12 inches ($0^{\cdot m}20$ to $0^{\cdot m}30$); and consequently the falling mass gradually became lighter the longer the stamp continued in use.

We may remark that, with the exception of the head, the principal parts of the stamping-mill were made of wood; but we must add that, as in the case of nearly all machinery used in dressing, wood has gradually given place to iron. The transition period is shown by fig. 488, which represents a stamping-mill erected some years ago at some dressing works in Rhenish Prussia.

The lifter, it is true, is still made of wood; but, on the other hand, the frame-work is composed mainly of iron. The cast-iron bed-plate is shown resting upon the masonry foundation to which

the frame properly so-called is bolted. Then we see two plates, one above the other, forming the bottom of the mortar, the iron cross-pieces connecting together two adjacent posts, to which are fitted small movable parts which constitute the guide-boxes in which the lifters work.

Lastly, stamps may be made entirely of iron, as shown in fig. 489, by using wrought-iron lifters. The head of course remains of cast-iron, and is fixed to the stem by means of wooden wedges, as there is a hole in the head formed like a truncated cone, whilst suitable notches are made on the stems.

(**643**) It is well to remark, that in constructing stamps, whether wholly or partly of iron, endeavours should be made to allow the striking and rubbing parts to be easily taken out and changed. If suitable arrangements are made to secure this object, the result will be, firstly, economy of time, because the stoppages will be shorter; and, secondly, economy of money, because the changing of a single piece will sometimes enable one to go on working a stamp for a long time which otherwise would have been quite useless. Thus the dies forming the bottom of the mortar, the guides, the extremities of the cams, &c., and *a fortiori* the heads,* should be fixed so as to be capable of being changed rapidly and easily.

The cam shaft is provided with cams, generally from 3 to 6 for each head, so that if the shaft makes 15 to 20 revolutions per minute, each head will drop 40 to 70 times. The curve of the faces of the cams is an involute of a circle; they are made of cast-iron, and are arranged upon the shaft spirally, so that they may act successively, and thus cause the strain upon the driving machinery to be constant.

The cams strike against the tongues or tappets fixed to the lifters, and raise them more or less according to their shape, and according to the position of the tappet, which can be made movable for this purpose; lastly, in the case of iron stamps, which are frequently round, an excellent arrangement† consists in cutting a

* A common plan is to have the *head* so arranged that a *shoe* can be fixed on under it, and replaced when worn.—*Translators.*

† According to Prof. Egleston, the screwed-tappet has been to a great extent abandoned in California in favour of the gib-tappet fixed by a gib and two steel keys.—*Translators.*

thread upon the lifter or stem, and screwing on the tappet, which is like a large nut with a broad base. As there is a certain amount of friction between the cam and the tappet, the stem turns slightly at each lift, and consequently the shoe, which always wears out most quickly on the delivery side, will preserve its regular shape till the end. With rectangular lifters this arrangement cannot be adopted, and the stamps must be reversed from time to time.

(644) In planning stamps there are three principal points to be considered, upon which their work is mainly dependent. These are the weight of the stamp, the height of the lift or drop, and the number of drops per minute.

From the conditions under which the crushing takes place it is evident that, if we wish to avoid producing an undue proportion of slimes, it will be advisable to employ light heads, with a long drop in order to give them sufficient force, and to work slowly, so that in the interval between the successive blows the stream of water may carry off all the stuff that is fine enough to pass through the grate or screen.

Of course the design must not be based upon these principles if it is necessary to stamp *dead*. In this case, on the contrary, we have to use very heavy stamps, and to drive them quickly, so as to get through more work.

In practice we generally find lifters of 110 to 165 lbs. (50 to 75 kilos.), and heads of about the same weight, which give the stamp a total weight of 220 to 330 lbs. (100 to 150 kilos.), the latter limit being nearer the average than the former.

The height of the lift is from 6 to 8 inches ($0^{\cdot m}15$ to $0^{\cdot m}20$), but it may be as much as 10 or even 14 inches ($0^{\cdot m}25$ or $0^{\cdot m}35$) in the case of very light heads. The number of drops per minute found by actual practice to be most suitable is from 40 to 70, but as a rule it is best to keep nearer the lower number.

However, the figures we have just given would be insufficient for very hard or very finely-disseminated ores; and on this account the stamps employed for tin ore in Cornwall, and gold quartz in California, are very much heavier. Each stamp weighs from 6 to 9 cwt. (300 to 450 kilos.); viz., the lifter 260 to 330 lbs.

(120 to 150 kilos.), and the head 400 to 660 lbs. (180 to 300 kilos.), the drop is from 8 to 12 inches ($0^{\cdot m}20$ to $0^{\cdot m}30$), and the number of drops from 50 to 60* per minute. In cases of this kind the results of actual practice will be the best guide.

(**645**) We must now explain finally how the ore enters the kofer or mortar, and how it is discharged.

The sides of the kofer are made of wood or iron, but the bottom generally consists of a piece of cast-iron, or of some hard mineral, such as quartz, rammed down very tightly, and lying either upon a slab of cast-iron or upon pieces of wood on end.

When the ore is stamped dry, which happens sometimes if the object is simply to reduce it to a certain degree of fineness without concentration, the kofer is left open in front;† and as fast as the ore is reduced to the desired size, a workman shovels it out, throws it on to a sieve in front of him, and then shovels back what will not pass through.

However, since the introduction of crushing-rolls into common use, dry stamping has been much less employed, and the stamping process is generally carried on with water.

In this case the kofer or mortar is closed all round save upon one or two sides provided with screens, which allow the ore to escape as soon as it has been stamped fine enough.

Sometimes the screen is in front,‡ sometimes there is one at each end. In the first case, the ore will be fed in behind under the middle head of the battery; in the second, the feed is at one end and the discharge at the other.

The screens or grates are made either of wire cloth, or, for fine crushing, of plates of sheet-iron§ perforated by a steel punch, with holes which are slightly conical. The side with the smaller apertures is turned inwards to prevent choking. The screens are 4, 6, or 8 inches high‖ ($0^{\cdot m}10$, $0^{\cdot m}15$, or $0^{\cdot m}20$).

* The number of drops in American stamping-mills sometimes reaches 90 or 100 per minute.

† This is not invariably the case, as ores are often crushed dry through screens fixed to the mortars.

‡ Sometimes the screens are both in front and behind (*double discharge*); or they are in front and at the two ends; or, lastly, they may be fixed on all four sides.

§ Sheet copper is also used.

‖ The height is 18 inches in some cases.—*Translators.*

The water is brought in by a pipe or launder, the amount required varying according to circumstances. As the particles have to be carried off by the water, it is evident that the coarser the stamping, the greater will be the amount needed.

The ore might be shovelled in directly by a labourer, if he could be depended on to do his work regularly; but this is a result that can never be attained with certainty, and it is better therefore to have recourse to automatic feeders.

The arrangements which have been invented for feeding mechanically are very numerous, but at the same time comparatively simple. They generally consist of wheels with blades made to revolve regularly. These blades take the ore from the mouth of a hopper, which is filled from time to time, and feed it gradually to the stamps, as shown in fig. 488.

(**646**) The amount of rock that is crushed by stamps varies considerably according to the weight and drop of the stamp, the hardness of the ore, and the degree of fineness required.

It is therefore difficult to give anything like precise general figures. We may say, however, that stamps weighing from 300 to 330 lbs. (140 to 150 kilos), making 50 drops of 7 in. ($0{\cdot}18^m$) per minute, could crush per head per hour, in the case of a soft ore—

2 cwt.	(100 kil.)	through a screen	with holes	of	$\frac{1}{2}$ inch	(12^{mm}).
$1\frac{3}{8}$ „	(70 kil.)	„	„	„	$\frac{1}{3}$ „	(9^{mm}).
$\frac{3}{4}$ „	(40 kil.)	„	„	„	$\frac{1}{25}$ „	(1^{mm}).

The amounts of water required would be respectively 8, 6, and 2 gallons (40, 30, and 10 litres), per minute.

The figures given above would not be applicable, however, in the case of a hard ore, and ought to be reduced to one-half, one-quarter, or even one-eighth, according to the hardness of the ore and the fineness of the grates.

Each of the stamps will require $\frac{1}{2}$ horse-power to 1 horse-power, according to circumstances.

[The following details concerning California Stamp Mills are extracted from Professor Egleston's paper in *Engineering* (vol. xxx. pp. 19, 85, 163, 256. London, 1880), which contains numerous illustrations and is full of valuable information:

	Dry Crushing Silver Mills.			Wet Crushing Silver Mills.			Wet Crushing Gold Mills.		
	Stanford Mill, at White Pine.	Raymond and Fly, at Pioche.	International Mill, at White Pine.	Meadow Valley Mill, at Pioche.	International Mill, at White Pine.	Eureka Mill, at Carson River, near Virginia City.	Keystone Consolidated, Amador County, California.	Hunter's Valley Mill, Mariposa County, California.	St. Lawrence, Newcastle, Placer County, California.
Number of mortars . .	6	6	6	6	6	12	8	6	1
Discharge of mortars . .	Double	Double	Double	Double	Double	Single	Single	Single	...
Number of stamps to each mortar . . .	5	5	5	5	5	5	5	4 with 4 2 with 6	6
Total number of stamps .	30	30	30	30	30	60	40	28	6
Weight of a stamp in pounds	750	750	750	750	750	950	750	650	650
Height of drop in inches .	8	8	7½	9	7½	9	8½	11	10
Number of drops per minute	95	95	93	85	87	90	85	70	90
Screens	Brass wire	Brass wire	Brass wire	Punched Russia iron	Punched Russia iron	Punched Russia iron	Slotted Russia iron	Punched Russia iron	Punched Russia iron
Trade number of the screens .	50	50	50	6	6	4	5	6	5
Tons of rock crushed in 24 hours . . .	52	48	33	67	47	159	90	50	17
Tons crushed per stamp in 24 hours . .	1·73	1·6	1·1	2·17	1·57	2·65	2·25	4 stamp 1·75 6 stamp 1·83	2·85
Quality of the rock . .	Hard	Easy	Soft	Tough	Soft	Easy	Medium	Easy	Brittle
Formation	Limestone	Quartz	Limestone	Quartz	Limestone	Quartz	Quartz	Quartz	Quartz
Fineness of the bullion .	·998	·775	·990	·550	·990	·980	·840	...	...

The diameter of the round holes, or width of the slots in the screens, expressed by the number 4, 5, or 6 in the above table, is the size of a sewing-machine needle of the same number. No. 5 is about $\frac{1}{16}$ inch.

As an example of stamping machinery for tin ore, we can refer to the stamps in use at West Basset Mine, described by Mr. John Hocking, jun., in the *Proceedings of the Mining Institute of Cornwall*, part ii. p. 23. Truro, 1877.

Steam-engine, 40-inch cylinder, 9-feet stroke, double-acting, condensing	
Number of heads	64
Quantity of tinstone stamped in a week . .	621 tons
Quantity stamped per head per day after allowing for stoppages	34¾ cwt.
Average weight of head and lifter . . .	877 lbs.
Quality of the rock	Hard *tinstuff*
Coal consumed for stamping one ton of tinstone .	61·3 lbs.
Quantity of water required for dressing purposes per head per minute	10 gallons
Cost of stamping alone, including coal (at 17s. per ton), wear and tear, depreciation of plant, and interest on original outlay . . .	1s. per ton

Among other kinds of stamps may be mentioned the Ball stamp, the Leavitt stamp, and Husband's oscillating cylinder stamp. The two former work like steam-hammers, the blow due to gravity being assisted by the pressure of steam. At the Calumet and Hecla Mine, Lake Superior, each Ball stamp is capable of crushing 130 tons in twenty-four hours. (Egleston, "Copper Dressing in Lake Superior," *Metallurgical Review*, vol. ii., New York, 1878.) The Leavitt stamp is an improved Ball stamp, and is taking the place of the older type; one head will crush 240 tons in 24 hours. (F. G. Coggin, "Notes on the Steam-stamp," *Trans. Amer. Soc. Mech. Engineers*, vol. vi. p. 370, 1884–85; *Engineering*, vol. xli. p. 119, London, 1886; *Eng. and Mining Jour.*, vol. xli. p. 210, New York, 1886.) Husband's oscillating cylinder stamp is an improved form of of his pneumatic stamps. Each head will stamp more than 20 tons of hard *tinstuff* in twenty-four hours. (M. Loam, "Husband's Oscillating Stamps;" and W. Derry, "The Duty and Maintenance of Husband's Oscillating Cylinder Stamps," *Proc. Min. Assoc. and Inst. Cornwall*, vol. i. pp. 57 and 68. Redruth, 1885.)—*Translators.*]

(647) We will pass rapidly over the mills, which are much less

suitable for crushing purposes than the machines already described, save under the special circumstances to which we have alluded.

We may remark, however, with reference to the mode of action of these well-known machines, that the stones may either be arranged like those of a flour-mill, so as to revolve round a vertical axis, or they may be placed on end so as to work like certain mortar-mills.

In both cases, and particularly in the second, the quantity of fine dust produced is very great; but when this is precisely the object sought for, the defect becomes a good quality. Indeed, in America, in grinding ores for amalgamation, they have gone so far as to make mill-stones on edge turn round a vertical axis without rolling, with the result of producing a larger quantity of fine dust.

(648) It follows, from what has been said in the preceding paragraphs, that the machines which may be used side by side for crushing purposes in dressing works are:

1. A stone-breaker, for breaking large lumps as they come from the mine, so as to facilitate the picking and cobbing.

2. Two or three pairs of rolls, the rings, shells, or tires being made of cast-iron or steel. These serve for treating fragments varying from 3 or 4 inches ($0^{\cdot m}10$) downwards, and reduce them by successive crushings and sizings to the dimensions of $\frac{1}{25}$ inch (1^{mm}) without its being possible to go much below this limit.

3. A few heads of stamps, for treating the mixed ore and waste (*dradge*) which cannot be crushed fine enough by the rolls, and reducing it to the state of very fine sand, or even slime.

However, this general arrangement may have to be altered owing to special circumstances which render it advisable to employ mills or stamps alone, as is the case at Mechernich, for the reasons explained in No. 637.

The subsequent treatment varies according to the machine employed for crushing.

Tho products of the stone-breaker fall on to a screen, and the stones which are thrown off by it are re-crushed and cobbed, whilst the stuff which passes through is washed and sized in trommels.

The stuff coming from the crushing-rolls is sized by trommels when of the dimensions of gravel or coarse sand, whilst the fine sands and slimes are classified by settling-pits, pointed-boxes, or other contrivances of this kind.

Lastly, the stuff coming from the stamps is always classified by apparatuses of this latter class, which are specially devoted to the fine sizes.

This series of operations is therefore thoroughly natural, and is consequently very generally adhered to in practice.

§ 2. Classification by Size.

(**649**) Sizing is an operation which directly follows crushing. Its object is to facilitate separation according to density, which depends upon a certain principle, and is effected by means of special machines.

The principle is the difference of speed with which particles fall in a fluid when their densities and volumes are different.

For the purpose of studying the law which governs this fall, let us first of all imagine a fluid at rest in which a particle of specific gravity D is falling. Let δ be the density of the fluid, a^2 the section of the particle at right angles to the line of fall, u its velocity. The three forces acting upon the particle will be:

1. Gravity.

2. The thrust of the fluid.

3. The resistance due to viscosity, which, as is well known, is proportional to the surface of the body as well as to the square of the velocity.

Putting $P = Ka^3 D$, the differential equation of the motion will be:

$$\frac{Ka^3D}{g}\,\frac{du}{dt} = Ka^3D - Ka^3\delta - K_1 a^2 u^2 \delta,$$

from which we get:

$$\frac{du}{dt} = g\left\{1 - \frac{\delta}{D} - \frac{K_1}{K}\,\frac{\delta}{aD}u^2\right\}.$$

We can at once deduce from this that none but identical particles

can fall in identically the same way; because to arrive at this result $\frac{du}{dt}$ must be the same, no matter what u is, and consequently:

$$\frac{\delta}{D} = \text{const.}$$

$$\frac{\delta}{aD} = \text{const.}$$

That is to say, we must have the same value for d and for a.

We may also deduce from this equation that in a shallow fluid, or, in other words, at the very beginning of the fall, before there has been time for u to become great, the motion takes place chiefly according to the relation

$$\frac{du}{dt} = g\left(1 - \frac{\delta}{D}\right),$$

and therefore solely according to density. The result of this is that machines which utilise only the first instants of the fall will have a high effect as concentrators.

(650) In order to examine what follows afterwards, we must integrate the differential equation in the following manner:

We may write—

$$dt = \frac{du}{g\left(1 - \frac{\delta}{D} - \frac{K_1}{K}\frac{\delta}{aD}u^2\right)}$$

$$= \frac{KaD}{K_1\delta g}\frac{du}{\frac{Ka(D-\delta)}{K_1 D} - u^2}.$$

Let us now put down:

$$A = \frac{KaD}{K_1\delta g},$$

$$B = \frac{Ka(D-\delta)}{K_1\delta}.$$

We get

$$dt = A\frac{du}{B - u^2}$$

$$= \frac{A}{2\sqrt{B}}du\left\{\frac{1}{\sqrt{B}+u} + \frac{1}{\sqrt{B}-u}\right\}.$$

The constant being equal to zero, we deduce

$$t = \frac{A}{2\sqrt{B}}\, l\frac{\sqrt{B}+u}{\sqrt{B}-u}.$$

From this we may deduce

$$\frac{\sqrt{B}+u}{\sqrt{B}-u}=e^{\frac{2\sqrt{B}}{A}t}$$

and consequently

$$u=\sqrt{B}\,\frac{e^{\frac{2\sqrt{B}}{A}t}-1}{e^{\frac{2\sqrt{B}}{A}t}+1}.$$

However little t increases, this value converges rapidly towards

$$u=\sqrt{B}=\sqrt{\frac{Ka\,(D-\delta)}{K_1\,\delta}}.$$

We might also find this value of u directly, because it is the one which ought to cancel $\frac{du}{dt}$. It will be reached as soon as the depth is sufficient for a regular state of things to become established, and it will be the same for all particles for which $a\,(D-\delta)$ has the same value; such particles are therefore called *like-falling, equal-falling* or *equivalent.*

The results of P. von Rittinger's experiments show that this value is quickly reached in water, and that in this case, δ being equal to 1, we may say

$$u=2{\cdot}44\sqrt{a\,(D-1)}.$$

The following table gives the results of these experiments, supposing a to be the diameter of a hole through which the particle has passed:

Nature of the Substance.	Specific Gravity.	Transverse Dimensions.	Values of the Velocity t.				
			⅛ second.	¼ second.	½ second.	1 second.	2 seconds.
		mm.	metre.	metre.	metre.	metre.	metre.
Galena	7·5	16	0·903	1·444	1·630	1·650	1·650
Pyrites	5·0	16	0·825	1·174	1·287	1·293	1·293
Quartz	2·6	16	0·570	0·767	0·801	0·817	0·817
Galena	7·5	4	0·704	0·814	0·823	0·824	0·824
Pyrites	5·0	4	0·586	0·643	0·646	0·646	0·646
Quartz	2·6	4	0·383	0·409	0·409	0·409	0·409
Galena	7·5	1	0·409	0·413	0·414	0·414	0·414
Pyrites	5·0	1	0·321	0·323	0·323	0·323	0·323
Quartz	2·6	1	0·203	0·204	0·204	0·204	0·204

This table shows plainly that the lighter and smaller the particle is, the sooner is the limit of velocity attained; but it also shows that even large and specifically heavy particles attain their maximum speed at the end of a very short time, less than one second.

(651) If we now pass from the case of particles falling without any initial velocity in still water to the case of there being a horizontal movement in addition, it is easy to see that the product of the diameter by the specific gravity must again be taken into consideration.

We may imagine two cases—either particles being carried along by a horizontal current, which partly overpowers their tendency to fall vertically, or particles with a certain horizontal velocity arriving in the midst of still water.

In both cases, as the forces acting upon the particle are proportional to the square of its transverse dimensions, and of its relative velocity with reference to that of the water, the differential equation of the motion will be an expression of the form

$$\frac{Ka^3D}{g}\,\frac{dv}{dt} = \pm K_1 a^2 v^2,$$

from which we deduce

$$\frac{dv}{v^2} = \pm \frac{K_1 g}{KaD}\,dt,$$

and

$$\frac{1}{v} = \frac{1}{v_1} \mp \frac{K_1 gt}{KaD}.$$

The result of this is that the quantity a D will be the ruling factor in the laws of the horizontal motion, just as the quantity a (D − 1) governed those of the vertical motion; hence:

1. In a horizontal current, the particles will acquire an increasing velocity, and those having the same value for a D will take the same time to reach the same distance, the curved path becoming flatter as the quantity a (D − 1) diminishes.

2. In a mass of water at rest, the velocity of particles arriving with a certain horizontal impulse will go on decreasing; but always so that like-falling grains, starting at the same instant.

find themselves at the end of a certain time in the same vertical plane.

(652) When the preceding theory is thoroughly understood, it is easy to deduce from it the laws for properly regulating classification by size.

As the time during which the density can exert a greater influence upon the fall than the dimensions is comparatively very small, we are generally obliged to take these dimensions into consideration, and this necessitates a preliminary classification by size.

We have seen that the equivalence of any two particles as regards their fall depends only upon the quantity $a\,(D-\delta)$, and if we wish to effect a separation by density, or, in other words, to concentrate the heavier particles out of a quantity falling in water, it is necessary that the particles of the densest substance should fall before the others; consequently, the largest particle of the lightest substance must be, at the most, equivalent to the smallest particle of the heaviest substance.

Therefore in the case of two particles, a, a', D, D′, falling in water, we must have

$$a\,(D-1) \geqq a'\,(D'-1),$$

or

$$\frac{a}{a'} \geqq \frac{D'-1}{D-1}.$$

In other words, the ratio between the smallest and largest dimensions must be greater than, or at least equal to, the inverse ratio of the densities each diminished by one.

The consequence is that if we classify an ore into several sizes, by means of perforated plates for instance, and if

$$a,\ a',\ a'' \ldots$$

represent the successive diameters of the holes, the values of these diameters must be in a geometrical progression with its ratio equal to

$$\frac{D'-1}{D-1}.$$

In this manner the classes into which the ore is divided will be such, that *falling through water will effect a separation* not only according to equivalence, but also according to specific gravity.

(653) If therefore we now take into consideration the specific gravity of the minerals commonly occurring in lodes, we shall be able at once to deduce the ratio of the progression which must be formed by the diameters of the holes of the sieves, or perforated screens, used for sizing.

Their specific gravities are:

Galena	7·6
Wolfram	7·5
Cassiterite	7·0
Mispickel	6·2
Iron Pyrites	4·9
Copper Pyrites	4·2
Blende	4·0
Heavy Spar	3·6
Calcspar	2·7
Quartz	2·6
Shale, with more or less Pyrites	1·5 to 4 (mean 2·5)
Coal	1·2

With these data for a starting-point, it is easy to see that in the case of a binary mixture of galena and quartz we have the ratio:

$$\frac{7{\cdot}6 - 1}{2{\cdot}6 - 1} = \frac{6{\cdot}6}{1{\cdot}6} = 4{\cdot}1.$$

Taking 4 as ratio of the progression, the maximum dimensions of the particles of each class will be:

1, 4, 16, 64 mm., &c.

This would be a very easy case of sizing.

For a mixture of coal and shale, we should have the ratio:

$$\frac{1{\cdot}5}{0{\cdot}2} = 7{\cdot}5,$$

which is also a very easy classification.

But if, on the contrary, we take a mixture of copper pyrites and blende, it is evident that the ratio would be reduced to

$$\frac{3{\cdot}2}{3} = 1{\cdot}06.$$

which would necessitate such a number of classes differing but little in size, that the idea of separation by water has usually to be

abandoned. In a case of this kind the copper pyrites must be separated as much as possible by cobbing. This is the way to reduce the loss to a minimum.

Lastly, if we are dealing with a complex mixture, it will be generally necessary to take into consideration the two constituents whose specific gravities are the nearest. If the sizing is based upon the ratio determined in this way, we shall be sure that the classification will *a fortiori* be sufficient for the other constituents.

Thus, when treating a mixture of blende, calcspar, quartz, pyrites, and galena, we should adopt the ratio:

$$\frac{7{\cdot}6-1}{4{\cdot}9-1}=\frac{6{\cdot}6}{3{\cdot}9}=1{\cdot}69.$$

If such an ore is sized by a series of screens with holes following a geometrical progression with the ratio 1·6, the classification is sure to prove effectual.

(**654**) These principles being laid down, we must now pass on to describe the machines by which they are brought into practice.

As the products of the operation of crushing are of all sizes, from $1\frac{1}{4}$ or $1\frac{1}{2}$ inch (30 to 35 mm.) down to the very finest impalpable dust, there are two kinds of classifying machines, according to the coarseness of the substance under treatment.

For stuff varying from the coarsest gravel to the finest sand, without going below a certain limit, which in practice is about 1 millimetre, we use successive sieves, or perforated plates, with holes varying in diameter according to the law just explained. The classification into various sizes is thus effected in a direct manner. But when the particles are less than 1 millimetre in diameter, the very fine meshes or perforations would not afford them easy passage, the sieves or screens would become choked, or would size unequally. We are consequently obliged to discard the direct method, and have recourse to an entirely different system, which will be described later on.

It is necessary therefore to make a decided distinction between the machines used for gravel and coarse sand, and those applied to the classification of fine sand and slime.

(655) Like the washing or cleansing apparatuses, the contrivances for sizing gravel and sand have undergone numerous modifications, which is not unnatural when we consider that these two kinds of machines are intimately connected with one another by the very nature of the operation. Moreover, the washing apparatus can be made to classify by size, by simply arranging one above the other several of the gratings mentioned in the preceding chapter, with smaller apertures at each step, so that each grating catches all sizes comprised between its own mesh and that of the one above it. But here also, as explained in the case of washers, it is obvious that, on account of their simplicity and easy working, trommels were destined sooner or later to replace all other kinds of sizing machines. This is what has happened; and it may be said that at the present day, as far as stuff of the size of gravel and sand is concerned, trommels are universally employed for sizing in all mines which are keeping pace with the times and no longer retain traces of the old appliances.

The construction of trommels is very simple, and precisely similar to that of the washers. A trommel is a cylindrical or slightly conical barrel of sheet-iron, divided into several sections, with perforations of different sizes. It revolves on its axis, which, if the shape is cylindrical, is slightly inclined, so as to cause the stuff to move along; and it receives a sufficient supply of water, either internally or externally, so as to assist the stuff to travel forwards and thoroughly separate the fragments.

(656) It is evident at a first glance that two kinds of arrangement may be adopted for a method of sizing. Either the finest or the coarsest particles may be got rid of first.

The first method requires only one trommel, carrying a succession of screens, each having larger holes than the preceding one. It has the defect of making all the stuff pass over the thinnest screens with the finest holes, and thus causes a great amount of wear, and necessitates the screens being changed after a very short time. Furthermore, the large lumps will always have a certain amount of fine sand sticking to them, no matter how much water is turned into the trommel; so that the fine is not completely

separated, in spite of the importance of preventing its escape with the coarse, both on account of its comparative richness, and of the somewhat considerable loss which would thus ensue.

The second method, on the contrary, consists in erecting a series of trommels one above the other, each one making only one size, and having smaller holes than the one above it. The stuff caught by each trommel will form a class of definite size, whilst that which passes through the holes is classified by the succeeding trommels. This plan, which is not uncommon, and which may be adopted if there is sufficient room and if the economic circumstances of the case permit, has the defect of requiring a considerable height, and so causing greater difficulty in feeding the trommels, especially with any stuff that has to be passed through a second time. It is true that this fault could be lessened by reducing the diameters of the trommels, but this would impair their work; besides, independently of these grave defects, the complication caused by this system in the way of belts, shafting, bearings, &c., the number of which is multiplied by the number of trommels, is, as a rule, sufficient to condemn it entirely.

(657) The arrangement which appears to present the greatest advantage in practice consists in a medium course, which sensibly diminishes the defects of the two systems, without much diminishing their advantages. It is the plan which is now generally adopted in German dressing-floors.

It consists in dividing the stuff into two perfectly distinct categories, usually coarse gravel and fine gravel, by a *separating trommel*, which as a rule immediately follows the washing trommel, and precedes two sizing trommels.

The separator has two screens, one inside the other. The first and inner screen is conical, of strong sheet iron, with holes of $\frac{3}{4}$ inch to $1\frac{1}{4}$ inch (20 to 30 mm.) It allows most of the stuff to pass through, and retains only the largest pieces, which are picked by hand. The second screen has holes of $\frac{1}{5}$, $\frac{1}{4}$, or $\frac{1}{3}$ inch (5, 6, or 8 mm). The stuff which passes through goes to a fine-sizing trommel, No. 2, and that which is caught is delivered to a coarser-sizing trommel, No. 1.

In this manner the wear of the fine screens of No. 2 trommel is very much reduced, because all the coarse gravel has been got rid of, whilst the thickness of the finest screens of No. 1 trommel is sufficient to resist its abrading action.

It is true that this separator has to a certain extent the defects of all concentric double-screen trommels; namely, that the inner screen may wear away without being noticed, and that when the damage is detected, it is not easy to repair it; but when used in the manner just described, the inner screen can always be made strong enough to stand for a very considerable time, and after it has served for a long term it will be better to replace it entirely than to repair it.

Each of the two classes made by the separator goes to a sizing trommel with duly-arranged screens; for the coarser sizes the holes will vary from $\frac{1}{4}$ inch to $\frac{3}{4}$ inch (5 or 6 to 18 or 20 mm.), whilst in the fine trommel they will be from $\frac{1}{25}$ or even $\frac{1}{50}$ inch (1 mm. or 0·5 mm.) to $\frac{1}{8}$ inch or $\frac{1}{6}$ inch (3 mm. to 4 mm.), the difference between the successive sizes depending upon the nature of the ore. In practice sufficient attention is rarely paid to the results of the simple calculation we have given above, notwithstanding the fact that a less complete sizing than is required by theory causes the subsequent separation to be less distinct or even impossible, whilst, on the other hand, the formation of too many sizes complicates the machinery unnecessarily, and adds to the first cost. It is true, however, that this second defect is less to be feared than the first.

A diameter of $\frac{1}{50}$ inch or even $\frac{1}{32}$ inch (0·5 or 0·75 mm.) is the smallest size that can be got by revolving screens; and even that, as well as the sizes just above it, can only be obtained by means of perforated copper, or zinc, or wire cloth; but screens of wire cloth wear out more rapidly than perforated plates.

(658) The most important numerical data concerning trommels are as follows:

The total length will naturally depend upon the number of divisions or classes that are made; and the length of each ring must be arranged (allowing for the inclination) so that the stuff

remains on it long enough for a complete separation. It is generally 2 feet 4 inches, or better 2 feet 8 inches or 3 feet (70, 80, or 90 centimetres).

The diameter must not be too small, and as a rule should not be less than 3 feet 4 inches (1 metre), save under special circumstances. The thickness of the sheet iron must be chosen so as to stand plenty of wear, without, however, going too far, as this would unnecessarily increase the dead weight and the chances of choking. For holes with diameters varying from $\frac{1}{25}$ inch to $2\frac{1}{4}$ inches, the thicknesses are from $\frac{1}{32}$ inch to $\frac{1}{8}$ inch (0·75 to 3 mm.)

Lastly, the ratio of the perforated to the unperforated part ought to be as large as possible, so as to increase the sizing capabilities of the screen; but we must not go too far, for fear of weakening the plates, and of having the holes so close that they will wear into one another. However, no precise rule can be laid down upon this point.

Sizing plant, such as we have described, and consisting, as shown in figure 490, of one separating trommel followed by two sizing trommels, is capable, at the ordinary speed of 8, 10, or 12 revolutions a minute, of treating 30 to 35 tons of ore in a day. The consumption of water will be 1300 to 1800 gallons (6 to 8 cubic metres) of water per hour, and the power required one or two horse-power.

(659) We have already seen, as is easily understood, that screens cannot be employed for sizing particles below certain dimensions; that is to say, for the stuff passing through the finest meshes or holes of the trommels just described. It has therefore been necessary to put into requisition a totally different system of classification.

From the very earliest times up to the present day this system has consisted in applying the laws which regulate the fall in water of bodies of different specific gravities, as set forth in Nos. 649 *et seq.*, and particularly under the conditions there described of a current carrying particles with it, and allowing them to settle down at points more or less distant from the origin.

Recollecting these remarks, we shall at once conclude that the classification so obtained will be by *equivalence*, and not strictly by size. We may therefore look upon the appliances we are about to describe as doing preparatory work, effecting a classification dependent both upon size and richness; each category then passes on to the finishing machines, which effect a final separation of the stuff into portions of greater or less richness.

All the fine has to be treated in this way. It is stuff which has traversed the finest meshes or perforations of the trommels, and it may be derived from various sources:

1. The washing of the smalls.
2. The sizing of crushed ore.
3. The stamps.
4. The fine stuff from the bottom of some of the dressing machines, such as the jigger.

All these products from various sources are treated together or separately, according to circumstances, or rather, according to the more or less perfect appliances made use of. We will now proceed to describe the most important of these classifiers.

(660) The first and oldest is the *labyrinth*. Although it plays a very much less important part than it did formerly, it deserves a somewhat detailed description.

It consists of a series of troughs, through which all the muddy water from the dressing-floors is made to flow; and the particles carried in suspension gradually settle down according to equivalence.

A complete labyrinth in the old days was composed of the following parts:

1. Two pits, one after the other, 4 to 6 feet ($1^{\cdot m}20$ to $1^{\cdot m}80$) long by 10 inches ($0^{\cdot m}25$) wide, the head rather deeper than the tail, so as to form a hollow for the ore to accumulate.

The first of these two pits caught the coarse sand and the second the fine sand; and much adhering slime would also have settled with it if the deposit had not been carefully stirred with a shovel, so as to set this slime free, and enable it to flow away and subside further on at its proper place, according to equivalence.

It was advisable to have as many of these pits as there were different sources of slime-bearing water, because each one would furnish a deposit of a different nature, requiring a different treatment either in the pit itself with the shovel or later on in the finishing machines.

2. The labyrinth, properly so-called, consisting generally of a series of troughs, or *strips*, about a foot wide by a foot deep, with scarcely any slope, or with a slope which diminished from the head towards the tail. These strips are still retained in some dressing-floors, but on a far smaller scale than formerly.

For instance, the slope for a certain distance was 5 or 6 millimetres per metre, then it was diminished to 2 or 3 millimetres, and finally the tail part was level. At the same time, if thought desirable, as was the case when dealing with very fine slimes, the velocity of the current could be reduced by increasing the width as the inclination diminished.

As a large number of strips would have caused too great a complication, it was usual to rest satisfied with one set for the rich slimes and another for the poor, each about 30 or 40 yards in length, which was generally enough for catching the substances in suspension.

In laying out a complete labyrinth, the following improvement, which is likely to be useful, might be introduced. It consists in putting longitudinal partitions into each strip, so arranged as to allow the orey water to run into a greater or smaller number of these partial strips at pleasure.

By this device, whether stamping finer or coarser, or whether stamping to one size, but with a greater or less number of heads, in other words, whether altering the quantity or quality of slimes, we are enabled, by closing or opening the entrances of some of the strips, to proportion the velocity of the current to the nature of the stuff held in suspension by it, and consequently to ensure the formation of the deposit under favourable conditions.

3. Pits 6 to 10 feet (2 to 3 metres) square, about 3 feet or more deep, varying in number (generally three or four), and communicating one with the other by wide launders. These slime-pits are

still retained in new dressing-floors, for the purpose of catching the slimes which, on account of the current, have not settled in the strips or in the pointed boxes, which will be described presently.

4. Lastly, when the ore settles with great difficulty there are one or two larger slime-pits for the same purpose as the smaller ones, but acting somewhat more effectually. At the end of these pits a trial *frame* was sometimes put up in order to test the escaping slime, and see whether it was sufficiently poor, and it was then allowed to run away into the river.

However, as clayey matter in suspension generally renders the water very dirty, it may happen that the miner will be obliged from local considerations to purify it considerably before allowing it to escape. In a case of this kind it will be necessary to erect a couple of reservoirs, each with an area of several hundred square yards, and turning the dirty water alternately into each of them, there let it settle. We may then do without some of the other slime-pits, and take the head of the deposit in the big reservoirs just where the stream enters. Practical trials will soon settle how much should be taken.

Although the appliances for classifying which we are about to describe have shorn the labyrinth of much of its importance, it nevertheless still remains as an almost indispensable adjunct to all dressing-floors, because none of these appliances will catch the very finest slimes produced with some kinds of ore, which require water perfectly at rest before they will settle, and which cannot be allowed to escape on account of their comparative richness.

(661) The first modification introduced into the system of classifying fine stuff by the labyrinth was that of Herr von Rittinger, who more than thirty years ago invented the *pointed* or *pyramidal boxes*, often known also by their German name *Spitzkasten.*

The complete system, as arranged originally, consisted of three or four boxes similar to the one shown in fig. 491, in the form of inverted pyramids, each being larger than the preceding one, and at a slightly lower level.

The following are the dimensions which Herr von Rittinger

gave to some pointed boxes in the Hartz, which treated 9 tons of finely-stamped ore in twenty-four hours:

	Length at the Level of the Water.	Width at the Level of the Water.	Depth.
First Box . .	5 ft. 8 in. (1·m73)	1 ft. 5 in. (0·m43)	3 ft. 9 in. (1·m15)
Second Box . .	8 ft. 6 in. (2·m60)	2 ft. 4 in. (0·m72)	5 ft. 8 in. (1·m728)
Third Box . .	11 ft. 4 in. (3·m46)	4 ft. 3 in. (1·m296)	7 ft. 6 in. (2·m304)
Fourth Box . .	14 ft. 2 in. (4·m32)	7 ft. 6 in. (2·m304)	9 ft. 5 in. (2·m88)

It is evident that on entering each box the current is suddenly slackened; the effect of this, as explained in No. 651, is to cause the particles to settle more or less quickly according to the amount of slackening, which depends upon the dimensions of the boxes and the connecting launders, and evidently becomes greater and greater.

When once the particles have sunk a little they escape the influence of the current, and quietly settle down to the bottom of the box. Here there is a hole leading into a pipe with a sectional area of about 1 square inch (25 mm. square), which is bent up so as to diminish the rapidity of the outflow, and the sand or slime runs out continuously without requiring an excessive supply of water.

The dimensions of the box are not the only data which affect the nature and quantity of the deposit; the results depend also upon the horizontal velocity of the current, and therefore upon the total quantity of water flowing into the box, because the quantity running off at the bottom is practically constant, as the head varies but very slightly. Thus we have a first means of roughly regulating the *Spitzkasten* by its general dimensions, which should be in harmony with the work to be performed; and a second, more delicate, but at the same time less powerful, means of regulating it, by the quantity of water supplied to it.

(662) Pointed boxes may be used for classifying the products of any fine crushing, either directly, or after the sand has been taken out by pits sloping backwards, such as are used at the head of a complete labyrinth. In the former case the outlet hole of the

first box is usually provided with a valve made to open and shut alternately, so as to avoid the choking which might result from the coarse sand coming in irregularly and falling rapidly to the bottom; in the latter case no such valve is required.

The proportion of slime deposited will depend not only upon the nature of the ore, but also upon the relative dimensions of the boxes, and the quantity of water. The following figures are given by Herr von Rittinger as the results of some experiments made by him in Hungary.

First box . . .	40	per cent. of the total quantity.
Second „ . . .	20	„ „
Third „ . . .	24	„ „
Fourth „ . . .	10	„ „
Total	94	per cent. of the total quantity.

This shows that about 6 per cent. of the total quantity escaped. In a case of this kind the effluent water must be led into slime-pits, where a final deposition will take place.

(663) The advantages of Herr von Rittinger's pointed boxes are:

1. Economy of labour, due to the fact that the product of the crushing machines can be sent directly, or at all events without any interruption, to the washing machines, by means of suitably-arranged launders leading from each Spitzkasten to the jigs or frames used for concentrating.

With the labyrinth, on the other hand, everything must be allowed to settle. The deposit must be dug out with the shovel, loaded on to barrows, and finally wheeled to the frames, which are occasionally at some distance.

2. Easier and sharper concentration, because the particles are thoroughly suspended in water, and flow regularly on to the frames, so long as the supply sent into the pointed boxes is regular.

With the labyrinth the case is very different, because the fine slime tends to become agglomerated and form a pasty mass, if it is allowed to settle; and when once it is in this state, it is difficult to get it into suspension and dilute the slimy water thoroughly, which is an indispensable condition for proper working.

We must remark, however, that the original form in which pointed boxes were constructed is not the most rational. The difference of section between the supply launder and the box causes a sudden change of velocity in the various little currents making up the stream. The result of this is the formation of eddies which cause irregularities in the working. It would be better therefore to place the communication of each box with the next one, at a level intermediate between the surface and the outlet orifice, so as to let it catch all that ought decidedly to pass through. If necessary, the effect might be assisted by a little shelf placed just below the outlet hole leading to the next box.

But whether made in this way or in the original form, pointed boxes are bulky and cumbersome; and as their size cannot be altered, the only method of regulating their action is by a greater or less supply of water. They cannot therefore adapt themselves to the variations which may occur in the nature or quality of the ore; in other words, they are not delicate enough.

One of the first modifications introduced was to make the boxes much lighter by constructing them of sheet zinc, and, in addition to sundry minor improvements, upon which we need not dwell, several launders were placed side by side, each with a separate hatch; and by opening a suitable number of them, proportionate to the quantity of ore supplied, the defect mentioned above could be overcome. However, all these apparatuses have now almost everywhere been replaced by *ascending current classifiers.*

(664) These classifiers consist of a series of vats, similar to the pointed boxes, at the bottom of which a current of clear water is introduced. The ascending current is made sufficiently strong to carry off into the next vat all the sand or slime which is too fine or specifically too light to resist its action, whilst the heavier particles subside to the bottom, whence they can be tapped off.

The result is, that the amount of the deposit is regulated, not by the size of the vats, which may be chosen much more at random than hitherto, but by the force of the ascending current. By regulating the current and making actual trials, we are enabled to obtain the class of ore we desire.

The application of this method has caused an entire transformation of the classifiers for sand and slime; for the principle is so simple, the regulating so easy, and the working so convenient, that they have been adopted unanimously in all progressive dressing establishments. But it is precisely on account of their general adoption in practice that so many varieties have been constructed.

The first and simplest plan consisted in fixing the clean water supply-pipe at the bottom of the vat, without changing the pyramidal shape of the latter. It was soon perceived, however, that this plan had the following disadvantage: As the vat gets larger and larger towards the top, the velocity of the ascending water naturally becomes less and less, so that many particles are able to settle down below the level of the overflow, but are then stopped there by the increased force of the ascending current. As the current is not strong enough to carry them over into the next box, the result is that an accumulation of particles takes place half-way up the box, and ultimately becomes so great as to seriously interfere with the classification.

(**665**) Several remedies have been tried for this defect.

By sharply opening the cock of the clear water supply-pipe just for a moment, the suspended particles may be carried off; but, independently of this method, other courses are open:

1. Instead of making the vat pyramidal throughout, it may be made prismatic, with a pyramidal bottom, as shown in Figure 492. The current is then uniform, and the defect just mentioned is considerably lessened.

2. Each vat or compartment may be made with its section decreasing, instead of increasing, from below upwards; the current then is stronger above than below, and any particle heavy enough to fall below the level of the outlet launder can no longer be forced to rise and escape. This arrangement is shown by the sketch, Figure 493.

3. Lastly, the clear water may be introduced, not at the very bottom of the box, but at a certain distance above it; so that when once a particle has dropped below the orifice of the pipe supplying clear water, it is subject simply to the descending

current, which tends to carry it downwards to the concentrating machines.

Figure 494 gives a complete drawing of a classifier of this kind employed at Steinenbrück, not far from the Rhine. It is used for treating an ore containing principally blende, with a little galena, and a very small quantity of spathose iron. In a working day of ten hours it will classify 20 tons of ore, requiring about 12 cubic feet ($\frac{1}{3}$ cubic metre) of water per minute.

It is easy to see that by having the compartments increasing in size, and by regulating the cocks bringing the clear water to the first three, these are made to catch the coarse sand, while the finer particles are deposited quietly at the other end.

(666) Such then are the classifiers most commonly employed in Continental dressing establishments for treating fine stuff. In practice they may undergo sundry more or less important and complex, but often useless, modifications of detail, according to the localities, and according to the fancy of the makers or engineers; but it may be stated in a general way, that *boxes with an ascending current*, supplemented by a slime-pit for stuff which is too light to settle in the boxes, constitute the simplest, most convenient, and most economical system for classifying fine sand and slime.

The variations introduced relate mainly to the number of boxes constituting the complete apparatus, and here the greatest uncertainty prevails. Engineers who are in favour of pushing classification as far as possible, naturally increase the number according to their own ideas, and may even have as many as fifteen or twenty. In this case the apparatus may be arranged so that the first boxes collect a finished product; but this is unusual, and the ore must be very rich before this is possible.

The greater or less complexity of the lode itself is the best guide, and the number of boxes should increase as the number of constituent minerals becomes greater. But however great the complexity may be, it must be recollected that the classifier has to work automatically without supervision, and has to supply

numerous dressing machines, consequently its chief characteristic should be great solidity and great simplicity, so as to avoid its getting out of order.

However, either for the purpose of treating certain special kinds of ore, or even without any well-defined object, save the desire of improving existing appliances, sundry somewhat complicated classifiers have been constructed. They are too well known to be passed over without at all events a brief notice.

The principal ones are: The Engis trough, the Thirion washer, the Dorr classifier, and the Mechernich siphon separator, which differs from the others in its mode of action.

(667) The *Engis trough*, like the classifier just described, is based upon the principle of the ascending current; but the manner in which the idea is carried into practice is somewhat different.

Instead of having a large receptacle containing a great quantity of water, with sand and slime in suspension, into which clear water under pressure is introduced for cleansing and classifying the particles, the orey stream and the clear water run along two distinct troughs, which communicate with one another. If the clear water is kept at a higher level than the orey stream, a current will necessarily flow from the former to the latter. By turning this current upwards it serves, as in the ordinary pointed boxes, to classify the particles.

The Engis separator, shown by figure 495, consists essentially of an inclined zinc trough C D, for carrying the orey stream, which is let down into, and partly enclosed by, the compartments for catching the classified deposit. The bottom of the trough is a grating composed of transverse hollow bars of zinc. The somewhat peculiar section of these bars is shown by figure *c*. They communicate with each other by means of two small longitudinal pipes placed below them, which supply them with water. Lastly, the trough increases in width towards the tail end, and rests upon the partitions separating the compartments which catch the deposit, and it communicates with these compartments by the spaces between the bars.

(668) We must imagine that the orey water is fed in at the head of the trough, and runs down it in consequence of its slope. All the compartments of the outer tank are full of water, each one running over into the next, and the level of the clear water is kept at a higher level than that of the ore stream; the clear water is therefore always trying to pass up between the bars into the ore stream. The mode of action of the machine will now be understood at once.

The particles passing over the spaces between the bars are more or less retarded in their descent by the ascending current, and a classification is produced like that of the ordinary machines.

The action is further complicated by an accessory arrangement which deserves attention. The hollow bars, as shown in figure *e*, are made with a slit, through which a second current of clear water escapes in an oblique direction; the obliquity increases from the head of the trough towards the tail end, and the effect of the second current assists that of the first.

The result is, that the particles are impelled by three currents:

The first, which is horizontal, or nearly so, carries them along the trough with a velocity dependent upon its slope.

The second, which is vertical, is the ascending current, due to the difference of level of the clear water in the outer tank, and the orey water in the trough. This is the principal agent for effecting the classification.

Lastly, the third, which increases in obliquity towards the tail end, comes from inside the bars, and adds its effect to that of the previous one.

As might easily have been foreseen, this very complication, which is perfectly useless, as well as several other minor defects, rendered it necessary to alter and modify the apparatus. The cost of keeping it in order was considerable, the stoppage of the dressing-floors during the frequent repairs was inconvenient, and it was soon evident that the two currents—one vertical and the other oblique—produced eddies which interfered with the classification. Even in the first compartments very fine stuff was sometimes deposited, which naturally injured the results of the subsequent washing processes.

The machine was simplified by doing away with the hollow bars and the zinc pipes which supplied them; then the form of the trough was changed, and the sides were made inclined, instead of vertical; and finally the bottom was made of a board, with transverse slits, inclined at an angle of 45°, in the direction of the current. These slits served to produce the ascending current, and to afford a passage for the heavier particles into the compartments underneath.

This simpler and improved form of the Engis separator differs from the ordinary classifiers by the method of communication between the trough containing the ore and the tank containing the clear water which is to wash and classify it, as well as by the number and shape of the openings for this communication, and the regularity of working resulting from this arrangement. It has, however, the defect of not emptying the compartments containing the classified products automatically; and the removal of the sand and slime by the shovel always causes a certain amount of disturbance in the classification, even when it is done regularly.

The Engis trough will treat 10 to 15 tons per working day of 10 hours, requiring 30 to 40 gallons (150 to 180 litres) of water per minute.

(669) The *Thirion washer* (Figure 496), based upon the same principle as the preceding one, is arranged somewhat differently. The clear water launder is placed alongside the one conveying the ore, and they communicate with one another by means of pyramidal boxes placed underneath them.

Each of these pyramidal boxes communicates with the clear water launder by a hole, which can be more or less opened or closed at pleasure by means of a conical plug attached to a rod with a screw-thread on it; the supply of water can thus be regulated to a nicety. The pyramidal box also communicates with the ore launder by a perforated plate, which permits the ascent of the clear water, owing to the difference of level in the two launders, and the descent of the particles of ore; these fall eventually into wooden hutches.

The force of the ascending current decreases from the head

towards the tail end, as the height of the cross partitions dividing the clear water launder into separate portions is diminished.

The Thirion classifier in this its original form had the advantage over the preceding one of giving a more regular pressure, and of consuming less water; but it possessed, on the other hand, several defects.

In the first place, it was somewhat complicated in construction, and could not be kept in order without trouble. It required much supervision and too many repairs, because the perforated plates wore out rapidly, the plugs which regulated the clear water supply frequently got out of order, often without being noticed; and lastly, the hutches for catching the classified products soon became worn out, and had to be changed. The expense caused in this way was by no means small.

Secondly, as regards working, the two vertical currents still produced eddies, which had a bad effect on the conditions of classification, which were already impaired by the nature of the holes through which the particles had to pass, as they did not afford a total area sufficiently large for ensuring regular working.

Lastly—and this is a natural consequence of what has just been said—the general result, whether as regards quantity treated or perfection of the classification, was by no means good.

Certain modifications were therefore made in the arrangement just described. The most important were:

1. Substitution of a board with transverse slits for the perforated plates. The slits were $\frac{1}{4}$ inch (7 mm.) wide, and inclined at an angle of 45°, in the direction of the stream. (Figures *e* and *f*.) This diminished the wear, and at the same time considerably increased the available classifying surface.

2. Substitution of a perforated pipe for the regulating plugs. The holes in the pipe could be stopped by pegs, as required, and the quantity of water increased or diminished at pleasure without any chance of a mishap.

3. Lastly, substitution of fixed bins, partly buried in the ground, for the little hutches, which wore out rapidly. The bins were arranged so that they could be emptied or cleaned out very easily.

Since these alterations have been made, the Thirion classifier has shown improved results, doing better work than the Engis trough; that is to say, it treats large quantities and classifies well.

(670) The *Dorr classifier*, which we will describe summarily, consists of a number of small zinc barrels, five for instance, of cylindro-conical form, arranged one after the other, either horizontally or vertically. In the former case the dimensions gradually increase, as the separation takes place in a manner similar to that of the classifiers just described; in the latter case the dimensions gradually decrease, as the classification is effected in the inverse order. A glance at fig. 497, which gives a sketch of the Dorr classifier, is sufficient to explain its mode of action. In reality it differs from the ordinary pointed boxes simply by the internal cones, which serve to spread out the stream of clean water, and render its effect regular. It is naturally not capable of treating large quantities of ordinary ores (only about four tons in ten hours), and it consumes too much water.

It would be much better to use a simpler form, say with one or two barrels, for separating in a simple ore two or three very different minerals, which it would do through the combined effect of size and specific gravity.

(671) However, for obtaining a result of this kind, preference should be given to the siphon separator (*Heberwäsche*), specially invented for this purpose at Mechernich by Herr Osterspey.

In principle it is based upon the ascending current; but as the pressure of this current is much greater than in the preceding classifiers, the discharge cannot be made continuous on account of the great loss of water which would ensue. It was therefore necessary to adopt a special arrangement for the purpose of regulating the discharge properly, which we will now describe.

The apparatus as constructed by the Humboldt Company at Kalk, near Cologne, consists of a wooden box divided by partitions into three compartments.

The central compartment contains the supply of clear water; this water passes under the partition into the second or classifying

compartment, the bottom of which is made of perforated sheet iron, with holes large enough to let water pass freely, but small enough to stop the grains of ore. In the centre there is a hole provided with a plug, which leads into the discharge pipe.

The grains which are heavy enough to overcome the ascending current fall to the bottom, accumulate there, and soon hinder the inflow of the clear water; the consequence is that the height of the water in the left hand compartment increases, raising a floating piston, which lifts up the conical plug by means of a suitable lever. As soon as the hole into the discharge pipe is thus opened the grains of ore rush in, and when the perforated plate is once more clear the clean water passes through, the floating piston and the plug fall, and the operation re-commences in the same way as before. The successive oscillations of the float are sufficiently rapid for the machine to work with perfect regularity.

The work is regulated simply by the greater or less height given to the piston; the influence of its position upon the level of the water, and hence upon the velocity of the current, is evident, and the machine can thus be rendered suitable for treating various kinds of ore.

The principal characteristic of this machine is the comparatively high water-pressure with which it works, and the property which it thus possesses of being able to treat enormous quantities if the ore is easily classified.

At Mechernich, where the ore consists of particles of galena disseminated through a comparatively light quartzose sand, the separator just described will treat fourteen to fifteen hundred tons of ore in twenty-four hours.

(672) In all the machines we have been describing, water has been chosen as the classifying medium, as was most natural; but attempts have been made to use atmospheric air for the same purpose, although it does not answer so well for the object in view.

The density of water permits it to act without too great an ascending force upon particles varying in size from impalpable powder to the coarsest sand; but air, on the other hand, requires

a comparatively rapid current for such sand. Moreover, if we recollect that the ratio of the progression which has to be maintained between two successive classes is given by the fraction

$$\frac{D-\delta}{d-\delta},$$

it is easy to see that for any given values of D and d the classes will be closer together, and the classification more difficult, as δ becomes smaller.

It is true that there may be circumstances under which a machine based upon this new principle can be applied with advantage; indeed, concentration by the pneumatic system, which is allied to pneumatic classification, is being tried in America, and appears to give good results. It will not therefore be a waste of time to give a summary description of some of the experiments made in this direction.

In the pneumatic classifier formerly employed at Engis, and represented by fig. 499, the air acts by a horizontal and not by a vertical current; this horizontal current carries the particles to a greater or less distance, as was shown in No. 651, according to the value of the expression a D.

The Engis pneumatic classifier consisted of a hopper fed by an elevator, from which the particles of various sizes fell into a long tube-like box, through which a current of air was forced by means of a fan. The section of the box increased from the head towards the tail, and the bottom was formed by two inclined planes, with a longitudinal slit between them, through which the classified ore fell into a series of bins, each larger than the preceding one. The first bins collected a highly-concentrated ore. At the end of the tubular part was a tolerably large chamber for catching the finest dust.

This classifier would treat 10 tons per shift of ten hours.

It had two principal defects, which raised the cost of classifying considerably, and finally led to its being given up:

1. It was necessary to dry the ore thoroughly, so as to make the particles completely independent of each other. As a rule the ore would have to be dried in special furnaces, as was the case at Engis.

2. It was necessary to provide a special motor for the fan, so as to avoid the alterations of speed, which would have ensued if the same motor had been driving other machines starting and stopping at any moment. This would have disturbed the proper working, because the greatest uniformity of speed is necessary.

But in spite of these defects, it is nevertheless true that under certain circumstances, for instance, in a very hot climate, and when the ore can easily be obtained in a state of complete dryness, and supposing also there is a great dearth of water, this machine might render very valuable services.

(673) Whatever classifier may be employed, it will be necessary, at all events with those first described, to fix the number of the compartments, and to regulate the supply of water, so as to obtain the kind of classification desired, either as regards quantity or quality.

We have already said that it will often be useless to make too many classes, as this would increase the cost of labour unnecessarily, and would complicate the general plan of dressing, without producing any sensible advantage. In order to get the best results, we must study the nature of the ore, its physical character, the specific gravities of the different minerals composing it, and regulate the classification by these data; and as a general guiding principle, we should take the axiom—that the simpler the ore, the simpler should be the method of treatment.

Furthermore, it will often be advantageous—and this is a point which should be examined with care—to eliminate at the very outset, by means of a proper supply of water, a certain quantity of the stuff, either for the purpose of throwing it away if it is barren, or in order to treat it separately if it is rich.

In the first case, which pre-supposes a light veinstone, we thus get rid in the beginning, and at a small cost, of a large proportion of very poor stuff which would otherwise notably increase the dressing cost. In the second case we separate from the rest of the stuff, and collect into a small volume, a certain proportion of the rich part, which may be sent directly to the smelting works, or may be treated again with greater care and often with greater

ease; at the same time we save almost entirely all subsequent cost of dressing it, and we prevent the considerable loss which would ensue from treating it in the midst of a lot of poor stuff.

The head of the classifier then becomes a true concentrating machine. It may also be converted into a cleansing apparatus, if the velocity of the current is regulated in the first compartments, so as to cause the deposit of all the gravel. We shall see later on that a thorough cleansing of the fine gravel from sand and slime is essential for good jigging. However, whatever may be the method employed, the operation of classification must be carefully planned originally, and vigilantly watched when at work, by the engineer in charge of a dressing establishment, because it is necessary—and we repeat it once more—to become thoroughly imbued with the idea that too minute a classification increases the cost considerably, and that too summary a classification renders the subsequent concentration more difficult and less perfect, and consequently that the economy and completeness of the separation are largely dependent upon this operation.

§ 3. Concentration.

(674) The classification of the stuff into as many categories as required by the more or less complex nature of the ore having thus been effected, we have now to consider the mode of carrying out the principal operation of dressing; viz., *separation* or *concentration*. This is sometimes very simple, but it is generally somewhat difficult.

However many classes may be made, they may always be placed under one of the four following heads:

1. *Coarse gravel*, the largest fragments being 1 inch to $1\frac{1}{4}$ inch (25 to 30 mm.), and the finest not less than $\frac{1}{2}$ inch (12 to 15 mm.). This is generally stuff thrown off by the trommels. We have already said that it is usually picked by hand, and we shall not refer to it again.

2. *Fine gravel*, stuff between $\frac{1}{2}$ inch and $\frac{1}{8}$ inch (12 to 3 mm.).

3. *Sand*, more or less coarse, retaining this appellation as long as the grains are perceptible to the touch.

4. *Slime*, an impalpable mud, more or less plastic, and requiring, on account of this plasticity, quite a special treatment.

These substances, which are generally comparatively poor, are subjected to a series of operations effecting a separation according to specific gravity, with the following objects in view:

1. To extract at once a certain quantity of ore fit for smelting, which thus escapes the loss which ensues in the subsequent processes.

2. To eliminate a very large quantity of waste, which may often still retain small specks of ore. This separation has the important advantage of greatly diminishing the total cost of crushing, because the waste is thrown away finally, and of avoiding the loss which, as already said, would inevitably result from treating an ore of average richness mixed up with so large a quantity of poor stuff.

3. To obtain, between these two classes, a certain quantity of *dradge*, forming a small proportion of the total, and consisting of particles of a mixed nature, containing the different metallic ores of the vein with a variable amount of veinstuff. This stuff is sent again to the crusher, though it is sometimes first of all returned to the machines producing it, so as to be more thoroughly separated. From the crusher it passes again into the general circulation, but in a finer state of division.

1. Treatment of the Gravel.

(675) In order to apply the laws of the fall in water which have been explained above, it is necessary to adopt an arrangement which will be continually bringing the particles into suspension, and allowing them to drop again; in other words, a series of blows must be imparted, and their magnitude must diminish with the size of the particles, in accordance with the equation which gives the value of the ultimate velocity:

$$u = 2{\cdot}44\sqrt{a(D-1)}.$$

This mode of action has the further advantage of constantly reproducing the initial period of the fall, where, as we know,

the specific gravity alone governs the drop, and of so giving a greater influence to the specific gravity than to the size.

The machines best adapted for this purpose are the *jiggers*, or *jigs*. These are sieves supporting the ore, which is raised and allowed to fall at rapid intervals by a current of water from below, and in this manner we can realize the theoretical conditions of the fall in more or less deep water. The jig is *par excellence* the machine for dressing, universally employed from the most ancient times because it was the simplest and most convenient, and its use has continued to our day, with the help of successive modifications, which have converted it into a machine of remarkable precision.

(676) The conditions for ensuring proper working are somewhat delicate. As regards the nature of the stuff treated it is necessary:

1. That the dimensions of the particles should increase in uniformity as the specific gravities of the constituent minerals become closer.

2. That the stuff should be thoroughly cleansed from slime, in order to prevent clayey matter from causing non-equivalent particles to adhere together, and thereby changing the densities, hindering the classification, increasing the cost, and lessening the yield.

3. That the particles should not be too small, because very fine stuff settles upon the sieve as a compact mass, and does not let water pass through it easily; this naturally would render the separation irregular.

Furthermore, as regards the machine itself, it is requisite:

1. That the size of the holes of the sieve should be suitable for the size of the stuff jigged.

2. That the machine should be constructed so that the particles are raised exactly vertically by the water, in order that they may fall regularly.

3. That the strokes are not too rapid, so as to give the particles time to arrange themselves according to density; but the rapidity of the strokes must be adapted to the size of the stuff.

Lastly, as regards the manner of imparting the motion, care must be taken to make the beginning of the stroke sudden, the

upward velocity of the water great, and the downward velocity comparatively small.

This last paragraph requires some explanation.

As the principal condition of a good separation is, that all the particles should be raised regularly, it might happen, if the current came in with a slight velocity at first and then gradually increased in force, that certain parts would be lifted up so as to afford the water a sufficient outlet, the consequence of which would be that the remainder of the ore would be left at rest.

It is necessary therefore that the water should come up under the ore sharply, and that, with this object in view, its level before the stroke should be a little below that of the ore,* in order that it may have time to acquire a certain velocity before striking it. The blow raises the ore and separates the particles, or at all events tends to separate them according to known conditions, so that the lightest ones will tend to rise to the top, and the heaviest to fall to the bottom.

In its downward course the water will carry down the particles in the same order; but with a view to prevent any shock upon the sieve, and to let the effect of gravity predominate also during the descent, the speed of the downward motion, as a rule, should be comparatively slow.

It is easy to understand that an action of this kind, repeated successively for a considerable number of times, will finally separate the mass into a number of layers, one above the other, arranged according to their specific gravities and richness.

(677) The different arrangements for carrying these theoretical conditions into practice have been very various; they may be brought under two principal heads; viz., jiggers with movable sieves, and jiggers with fixed sieves, or piston jigs.

The former, whether worked by hand or by machinery, are characterized by the fact that the sieve itself is moved up and down in a vat full of water. During the downstroke of the sieve the water passes through the holes, raises the particles, and effects a separation.

* This is not always done in practice.—*Translators.*

In the latter, which are generally worked by machinery, the same effect is obtained by forcing water by means of a suitably-arranged piston through the meshes of a fixed sieve.

The jiggers with fixed sieves may be subdivided in their turn into discontinuous jigs, in which the stuff is treated in separate lots, which are put on and jigged by themselves, and continuous jigs, in which the charging and separation go on without interruption, and, so to say, automatically.

(678) *Hand jiggers* represent the original form of the machine. At first they consisted of small round or rectangular sieves held in the workmen's hands, and then came a better form in which the sieve was fastened to a pole hanging from an elastic beam.

Fig. 500 represents a further improvement, as the sieve is balanced more or less completely, and worked by a lever. This jigger consists of the following parts:

1. The vat or hutch, made of deal, provided with guides for making the sieve move vertically.

2. The sieve hung by an iron rod from a lever.

3. The lever, with counterpoise weighing from ¾ cwt. to 1 cwt. (40 to 50 kilos.) at one end, which lightens the work.

The sieve is 15 to 20 inches (40 to 50 centimetres) in diameter, and is made of woven iron wire proportioned to the size of the stuff treated. The wire cloth is stretched upon an iron ring which is fixed inside the wooden drum, and kept up by four crossbars; the drum is from 6 to 8 inches (15 to 20 centimetres) deep.

The tools employed are:

1. The *limp*, a piece of sheet iron, with one of the edges bent up at right angles, which is used for taking off layer after layer of the deposit on the sieve.

2. The *spreader*, another piece of sheet iron, for spreading the stuff on the sieve.

3. The *rake*, for drawing the charge into the sieve, from the little shelf where a supply has been placed.

(679) The workman partly fills his sieve with ore, and after having spread it out evenly, lowers it into the water, and gives it

a succession of shakes; the amount of the shake varies according to the size of the ore upon the sieve, and the number of strokes according to its richness and the nature of the product to be obtained. The shakes must be given in the manner explained, and the proper motion is quickly picked up by workmen.

The number will be from 80 to 100, or even 150 per minute; the length of the stroke varying from $1\frac{1}{4}$ to $2\frac{1}{4}$ inches (30 to 55 mm.) The operation lasts 5 or 10 minutes. Although very simple in theory, it admits of a host of variations in practice.

If the ore is rich, there is very soon a layer of ore fit for the smelter on the bottom of the sieve, which may be collected at once and sold, whilst the stuff composing the upper layers ought to be treated over again in the same jigger when a sufficient quantity has accumulated, or it should be re-crushed.

If the ore is poor, no concentrate sufficiently good for smelting is found until a very large number of strokes have been given, and even then there is little of it. The operation is therefore stopped long before this point is reached, and the top is skimmed off, leaving a layer decidedly richer than the original stuff. Another charge is treated in the same way, and so on for several times. Finally a layer of ore fit for smelting accumulates on the sieve.

We must furthermore remark, first, that it may sometimes be advantageous to pick the large pieces carefully by hand, especially if the veinstuff is heavy, and the separation on that account less sharp. In certain cases this hand-picking may be quite indispensable. This operation is generally carried out by children, because it requires little strength, and cannot be performed economically without that quickness of eye and hand which is easily found amongst the young.

Secondly, that some fine stuff will always fall through the sieve to the bottom of the tub, because the gravel ore is never washed quite clean. This *hutchwork* should be kept and treated subsequently by the fine jigs, which will be described later on.

With regard to the general arrangement, it is well to add that three or four jigs can be put up one after the other, each one treating stuff of a different size, or certain classes formed by the first jig, which may then be looked upon as simply doing preparatory work.

(680) In order to convert the hand jigger into a mechanical jigger, all that is necessary is to use some kind of machinery for imparting an up-and-down motion to the rod carrying the sieve. There are many methods of doing this. One of the simplest is to fix at the end of the lever a cam-wheel, shown by dotted lines in the figure, and a wooden spring. The sieve is brought down suddenly by the spring, when the lever is released by a cam, and is returned to its original position gently by the next cam. The conditions necessary for good jigging are thus properly realised.

As wooden or india-rubber springs (for these have been tried) are liable to get out of order, a more ingenious contrivance—the differential link—is usually employed.

Let O A (fig. 501) be a crank turning round the centre O, and carrying at its extremity A a pin sliding in a link A B movable around the point O'; it is easy to see that if the crank O A rotates uniformly, the descending motion of the piston P, which takes place whilst the point A describes the small arc $c\ c'$, is much sharper than the ascending movement, which lasts all the time of the revolution $c'Ac$.

Figure 502 shows how this plan has been realised in actual practice.

The advantages can be still further increased by making the line $O\ O'$ inclined at the angle of 45° to the horizon. The speed of the downstroke is increased, whilst the time taken for the upstroke and the pause is much greater.

(681) However, the arrangements just described, or other plans of driving jiggers by machinery, have not been adopted unanimously, for the two following reasons:

In the first place many engineers, especially in England,* were of opinion that mechanical contrivances could not take the place of the labourer in giving the jerky stroke, which theory and long practice show to be the best; but facts seem to show that this idea is erroneous, and that in reality a better separation is effected by the machine jigs.

* The prejudice against machine jigging is a thing of the past in England and elsewhere.—*Translators.*

Secondly, the economy of labour, which at first sight appears likely to result from the employment of machinery, is not so great as might be thought, because it is necessary in either case to have a workman for each jigger, and any saving in labour is partly counterbalanced by the cost of the motive power and repairs,

However, mechanical jigging does offer decided advantages. which are:

First, a more perfect separation, although this opinion has not been adopted unanimously.

Secondly, and more especially, the possibility which it affords of confiding the work to less-practised and therefore cheaper workmen; and, from a different point of view to the one just mentioned, this diminishes the cost of labour, especially in countries where labour is dear, without injuring the quality of the work.

(682) Jiggers with fixed sieves differ from the preceding ones by the fact that the upward current of water required for lifting the particles is produced by the action of a piston.

There are a great number of different kinds of these jiggers, which may be classified as follows:

As regards their arrangement, there are jigs with a side piston, jigs with the piston under the sieve, jigs with one or more sieves.

As regards their method of working, jigs may be continuous or discontinuous.

The first jigs with fixed sieves were worked by hand. Figure 503 shows a double-sieve jig formerly employed in the Hartz. The work was carried on in the same way as on a movable sieve.

It consists of a rectangular vat divided into three compartments. In the central one a piston moves up and down vertically, with a play of $\frac{1}{8}$ to $\frac{1}{6}$ inch (3 to 4 mm.) between it and the sides, so as to diminish the suction which would otherwise be produced on raising it. The water passes through the openings *d d'*, which, if thought desirable, can be closed alternately by little hatches, into the adjoining compartments, and raises the charges upon the sieves. The openings *d d'* occupy the whole width of the side, and their height, depending upon the coarseness of the

stuff jigged, varies from 4 to 8 inches (10 to 20 cm.). The bottom of the pumping compartment is always horizontal, whilst that of each sieve compartment is generally inclined towards a hole for the discharge of the fine stuff which passes through the sieve.

In order to drain off the water from the charges without losing all the water in the hutch, openings *n n* are made at the level of the sieve and just below it. These are kept shut by means of hatches.

Lastly, the width of the ore compartments, like that of the piston, is about 1ft. 8ins. to 2ft. (50 to 60 cm.), and the sieve is fixed at a depth of 10 inches (25 cm.). With coarse gravel ore the sieve is made of cast-iron, with long holes $\frac{1}{8}$ inch wide; and for fine gravel ore it is constructed of parallel iron wires, lying upon a wooden frame and wooden cross-bars, strengthened by strong sheet-iron. The distance between the wires depends upon the size of the stuff treated.

(683) The working data—that is to say, the thickness of the layer of ore put on, the stroke of the piston, the number of strokes per minute, the length of each operation, &c.—are likewise dependent upon the size of the stuff.

Generally the depth of the charge of ore varies from 5 to 6 or 8 inches (12 to 15 or 20 cm.), whilst the apertures of the sieve are from $\frac{1}{25}$ to $\frac{1}{8}$ inch (1 to 3 mm.) wide. Forty or fifty strokes are given per minute, varying in length from 4 to 6 inches (10 to 15 cm.), and being longer for coarse gravel than for fine.

The operation of jigging is conducted as follows:

The charge having been properly spread out upon the sieve, the workman turns on water into the pumping compartment, and sets the piston to work. He shuts off the water as soon as the ore is completely covered.

After allowing the machine to work for 5 or 10 minutes, he stops it by raising the piston, so as to throw it out of gear with the cams. This causes some water to flow from the sieve compartments into the pump-box, and, if the jigger is properly constructed, the level of the water should fall to that of the sieves.

If, however, it still covers the ore, it can be run off by opening the apertures *n n*, mentioned above, for a few moments.

(684) Before proceeding further with the study of jiggers, it will be well to dwell upon a somewhat delicate point, viz., the distance at which the opening from the pumping compartment should be placed below the sieve, because its position exerts a very powerful influence upon the regularity of the separation. According as it is placed too high or too low—that is to say, near the bottom or near the sieve—the action of the water is almost *nil* upon the ore nearest the pump and much stronger on the other side, or *vice versâ*. The defect is much more noticeable when the piston is small, for then it is necessary to work it at a higher speed.

In order to avoid the irregular separation which would result from this unequal action, the bottom of the ore compartment is made cylindrical; care is also taken to place the opening about half-way between the bottom and the sieve, and the speed of the piston is regulated by experiments with each kind of ore, so as to obtain a thoroughly regular action. It will generally be found that the jigger works properly when the water is driven just up to the opposite side, but with so slight a velocity that it is not reflected, causing eddies which would interfere with the results.

These defects can also be overcome by jiggers with the piston underneath, which do much better work than badly-made side-piston jiggers. The piston is placed exactly below the sieve (fig. 504), and a glance at the figure shows how regular the action ought to be.

The only point requiring a more detailed explanation is this:

In order to avoid too sudden a downward suction in the charge, which would not fail to occur on the descent of the piston, a special device had to be adopted. The hutch is made with double sides, and small passages *p p*, communicating with the outside, let air in under the piston during its ascent; during the downward stroke the air escapes through the central valve *S* in the piston, and fills up the space behind it. At the following stroke this air is pressed against the ore, and discharged by side openings *o* left for this purpose.

The arrangements described above for imparting the reciprocating motion by means of machinery may be applied with advantage to jiggers with side piston, or piston underneath, just as well as to the jiggers with the movable sieves.

(685) The greatest improvement introduced into the machines we have just described, but principally applied, it is true, in treating fine gravel ore, has been their conversion into *continuous jiggers.* To understand their mode of action and its consequent advantages, we need simply say that the stuff is fed continuously on to one end of a rectangular sieve, is there separated, and is finally discharged automatically and continuously, either in the form of waste or of clean or concentrated ore.

Numerous ingenious arrangements have been employed for this purpose; but we shall merely describe two or three of the principal ones, which will be sufficient for understanding the ideas which have led to their invention.

As a rule they consist in providing one or more discharge orifices at the proper height, that is to say, at the level of the layer of proper concentration, which is being produced by the jigging action; some device is then added for regulating the discharge at pleasure, according to the richness of the ore and the amount of concentration desired. During this time the greater part of the waste, more or less completely deprived of the valuable constituents, escapes over a barrier at the other end of the sieve.

Often, and especially when the ore is complex, two or three sieves are arranged in a line one after the other; the first receives the crude ore, and the next one takes what passes over from the first, and so on.

(686) One of the commonest arrangements, the newest type of double-sieve jigger, is shown in fig. 505. It is in use at the dressing-floors at Vieille Montagne. There are two oval discharge orifices at different heights above the sieve, each leading into a steeply-inclined pipe, generally made of lead, as this is easily fixed and does not rust; and a zinc gutter, which can be raised

or lowered by a wire, furnishes the means of blocking up the end of the pipe.

If we now suppose the jigger to be at work, its action will be easily understood as follows:

The ore falling regularly from the hopper passes on to the first sieve, and there undergoes a first separation; the heaviest particles at once subside to the bottom, and find an exit by the lower tube, whilst a rich mixture escapes by the second tube at a higher level. At the same time the remainder is carried by the water over the partition on to the second sieve, where it undergoes a second separation; two other classes of mixtures (*dradge*) are discharged by the pipes, and finally the waste passes over the end.

It is easy to see that by raising or lowering the gutter at the end of the pipe the discharge of the ore can be regulated to a nicety; with a slow discharge the stuff will be subjected for a longer time to the jigging action, and we are thus enabled to obtain precisely the kind of concentrate we wish. In the second place, there is also the great advantage of being able to supervise the working of the machine, because the discharge is continuous, and a glance at any moment shows the nature of the concentrate, a small quantity of which always remains on the gutter before falling into the box placed to catch it.

Lastly, we must notice the cylindrical shape of the bottom of the vat or *hutch*, the object of which is to remedy as completely as possible the defects of the side piston, which have already been pointed out; the valve at the bottom is for the discharge of the slime, which is found even among well-washed particles of ore and passes through the sieve.

Although the discharge of the concentrate can be regulated with nicety, it may fairly be objected that this system creates a centre of suction in the side, which tends to draw towards it not only the stuff in the layer at its own level, but also stuff from above, and so introduces a disturbing cause which it would evidently be advisable to avoid. To remedy this defect the small oval holes of the last jigger have been replaced by a low horizontal slit, the height of which can be altered at pleasure, as shown in fig. 506, which represents the arrangement adopted at Moresnet, or by

discharge trays occupying the whole width of the jigger, as shown in fig. 507.

In this latter form, the one in use at Bleiberg, only the waste and mixed products pass over the trays at the end, and the discharge is regulated by raising or lowering the inner edge of the tray, so as to increase or diminish the size of the outlet. The heaviest ore, which consequently lies upon the bottom, is discharged, on the contrary, by a vertical pipe fixed to the sieve, the orifice of which can be more or less closely covered by a plate of sheet iron; but as far as this product is concerned, we fall back into the defect just mentioned, and it would be better to discharge it over the end like the waste and the mixtures.

(687) The system of the central discharge tube has been applied on a larger scale in the so-called *bell-jiggers* of Moresnet (fig. 508). In the bottom of the sieve discharge-pipes with sliding caps are fixed. The discharge-pipe has an aperture at a certain distance above the sieve, and the ore passing through it is delivered outside. The sliding cap, which can be raised or lowered at pleasure, allows the concentrate to be collected at the most suitable level.

It is evident that, as the whole weight of the stuff on the sieve presses at each stroke upon the little column of ore in the pipe, an effect like that of two communicating vases is produced, and that the concentrate will rise up to the aperture and there escape.

If we suppose d to be the mean density of the layer of ore at the base of the cap, which is the only stuff that passes up and is discharged, h the distance between the aperture and the sieve, d_1 the mean specific gravity of the ore, h_1 the difference of level between the sieve and the upper discharge tray, it may be stated as an approximation that the discharge will take place in consequence of the relation:

$$hd = h_1d_1.$$

The particles in the pipe will always be endeavouring to rise high enough to be in equilibrium with the outside ore, but meeting with the aperture they escape by it.

The inferences to be drawn from what has just been said are:

1. That the degree of concentration obtained will depend, irrespective of all other considerations, upon the height of the base of the cap and of the aperture above the sieve.

2. That the rate of discharge of the ore will depend upon the mean density of the ore, and that consequently it will be independent of the quantity fed in by the hopper, and will vary only according to its quality. When once the cap is regulated for a definite kind of ore, the jigger will go on supplying a regular product of a constant specific gravity.

We see, therefore, the essential difference between this jigger and the preceding ones.

In these, the greater or less degree of concentration depends solely upon the rate at which the stuff is fed in from the hopper, and the contraction of the discharge orifice; in other words, it depends upon the time devoted to the treatment of each portion of the mass supposed to be taken alone. The result is that the products vary if the quantity of stuff supplied to the machine changes, or, in other words, if the feed is not perfectly regular.

In the bell-jigger, on the contrary, the quality of the product depends solely upon the quality of the ore fed in, and is almost independent of the quantity. This fact gives the bell-jigger a certain advantage, which is however fully counterbalanced in the other jiggers, by the ease with which regularity of supply can be ensured by mechanical feeders, as well as by their greater simplicity, and by the readiness with which they can be watched.

(688) We have by no means described all the arrangements which may be adopted for the discharge of the jigged ore, and it would be difficult perhaps to say very decidedly which is the best; but whatever arrangement may be selected, it may be said generally that two, three, or even four sieves may be arranged one after the other, as shown in figure 505, according to the more or less complex nature of the ore. This plan enables us to make several products, and to vary the nature of each by altering the size and adjustment of the discharge orifices.

Thus in the simplest case—viz, that of a mixture of a heavy

ore with a light veinstone—we may be able to do with one sieve discharging the concentrate underneath, and letting the waste pass over the end. But this is a somewhat rare case, and more often we have to deal with more complex mixtures.

Thus if we are treating a mixture of galena, blende, spathose iron and veinstone in the two-sieve jig shown by figure 505, we may get:

From the first sieve: by the lower tube, clean galena fit for smelting; by the upper tube, a mixture of blende and galena which requires re-crushing.

From the second sieve: by the first tube, blende more or less mixed with spathose iron, but clean enough for smelting; by the second, a more complex mixture of blende, spathose iron and waste, which must be crushed over again.

The waste will pass over the end of the jigger.

Lastly, to illustrate a still more complicated case, we may take a three-sieve jigger with central discharge pipe and two end discharges, like those described in No. 686, and suppose it to be treating a mixture of galena and blende with pyrites.

We may then have the following results, which, as we know, can be modified to a certain extent by altering the size of the discharge apertures:

FIRST SIEVE.

1. Hutchwork (stuff passing through the sieve) .	Galena fit for smelting.
2. First discharge tray . .	Galena mixed with pyrites and blende.
3. Second discharge tray, leading to the second sieve .	Mixtures.

SECOND SIEVE.

4. Hutchwork . . .	Pyrites mixed with a little blende and galena.
5. First discharge tray . .	Blende mixed with pyrites.
6. Second discharge tray, leading to the third sieve .	Blende and waste.

THIRD SIEVE.

7. Hutchwork . . .	Blende.
8. Discharge . . .	Waste.

In carrying out the work, the number and length of the strokes are determined once for all, for a certain size and quality of ore, by practical trials made by the foreman of the dressing-floors. For instance, the number of strokes may vary from 50 to 100 or even 150 per minute, and the length of stroke from $\frac{5}{8}$ inch to $1\frac{1}{2}$ inch or 2 inches (1·5 to 4 or 5 cm.).

The quantity treated and the consumption of water depend entirely upon the nature of the products required and the speed of working. The quantity may vary from 3 or 4 to 10 or 15 tons a day, with an expenditure of 4 to 22 gallons (20 to 100 litres) of water per minute.

(689) Many other varieties of continuous jiggers might certainly be described, but those we have examined are quite sufficient for understanding the mode of working of all machines of this kind.

Each may possess certain slight advantages over the others, according to the circumstances under which it is employed, but they are chiefly remarkable for being manifestly better than the discontinuous jiggers. This superiority is principally due to the enormous diminution of hand labour, which renders it possible to treat very poor stuff by eliminating at the very outset the greatest part of the waste, and producing a more or less rich concentrate, which can be afterwards treated in a more careful manner, either in the same machines, or even in discontinuous jiggers.

As a natural consequence, continuous jigs are employed, both on account of their convenience and of their economy in working, whenever they can possibly be used. Unfortunately this is not always the case, for experience has shown:

1. That the work of continuous jigs is very imperfect with gravel more than $\frac{5}{8}$ inch, $\frac{1}{2}$ inch, or even $\frac{3}{8}$ inch (15, 12, or 10 mm.) in diameter, as the discharge of stuff of this size cannot proceed with as much regularity as that of fine gravel; for the mass is not, so to say, fluid enough to spread out rapidly into layers of equal density and flow out evenly.

2. That the work is equally unsatisfactory, though for a different reason, with sand of a smaller size than $\frac{1}{25}$ inch (1 mm.). In

this case, on account of the resistance of the water, the effect due to gravity becomes less and less marked as the fineness of the stuff increases; and furthermore, this fineness gives the mass a certain degree of cohesion, a sort of plasticity, which prevents it from responding properly to the call made by the discharge orifices.

The consequence of this is that discontinuous jigs are still employed for coarse gravel, and so constitute a necessary intermediary between hand-picking and continuous jigging. On the contrary, for treating fine stuff smaller than $\frac{1}{25}$ inch (1 mm.), we must resort to other machines, of which many kinds are to be found. The most perfect, which have been invented comparatively lately, are the Hartz jigs, so called from the country of their birth. Their mode of action is decidedly different from that of the jigs we have been considering. They will be described later on.

(690) In order to ensure proper working, jigs must be fed with the utmost regularity.

It is easy to devise means to effect this result. Sometimes a mere sliding hatch is employed (Figure 505), which can be raised or lowered at pleasure, so as to increase or diminish the outlet, and a jet or two of water is turned in to cause the stuff to run down. In other cases the bottom of the hopper lies imbedded in the stuff on the sieve, and at each stroke a little comes down to take the place of that which has gone away.

But it is better to ensure perfect regularity of feed by a simple contrivance employed in many analogous cases; viz., an endless screw.

Figure 509 represents the form adopted by MM. Huet and Geyler. The charging hopper is provided underneath with a sort of cast-iron pipe containing a screw driven in any convenient manner from the shafting of the works. The screw receives the stuff between its blades and conveys it to the end of the tube, where it falls through an opening on to the sieve.

Whatever may be the method employed, we must fully recognize the fact that it is impossible to separate properly without beginning by feeding regularly. When the stuff is fed regularly it

always spreads over the sieve in the same manner, is treated for the same length of time, receives the same number of strokes, and the result is that the products are constant in quality.

2. Treatment of Sand.

(691) For the reasons just given, the method of treating sand was formerly quite different from that which we have described in the case of gravel ore. In former times, and even at the present day in dressing establishments which have not had time to renew their plant, the concentration of sand was effected by bringing it into suspension with water, and running the liquid on to an inclined surface, diluting with clean water, and working the deposit with a rake or broom, or by a series of shakes imparted to the apparatus, and lastly purifying by a stream of clean water.

In order to explain the effect of these operations, we must first of all recollect the equation which governs the fall of particles in shallow water (*see* No. 649),

$$\frac{du}{dt} = g\left(1 - \frac{\delta}{D}\right),$$

which shows the preponderating effect of specific gravity.

The effect foretold by the formula is precisely that which occurs in treating sand, but it is complicated by certain accessory actions.

When a deposit is being formed on an inclined plane, there is a sort of elimination of the largest particles, which, under the impulse of the current, tend to roll down the more or less rough surface of the deposit already formed; whilst the smallest ones are kept back, imbed themselves in it, and so become comparatively sheltered from the action of the current.

The raking, which is constantly bringing the stuff back into a state of suspension, allows the effect just mentioned to be repeated frequently; it furthermore mixes the stuff up, and helps to get rid of the muddy or slimy particles which easily become suspended in water.

In the same manner, if the surface upon which the deposit is forming is shaken more or less violently, the shakes produce a

similar effect by the direct action of the shock, and by the vibratory movement caused by it.

We must add, however, that these actions never have the sharpness and precision which the theoretical conditions laid down above would require, for we start with a more or less clotted and thoroughly heterogeneous mass, the individual particles of which are not free to move with entire independence; but, on the contrary, they are continually influencing and counteracting each other in the irregular movements caused by the current.

(692) The oldest apparatus employed on the Continent for treating sand is the German buddle. It may still be seen occasionally, though it is fast disappearing. It owes its name to the country where it was invented, but it is also known as the *grave buddle* on account of its shape.

It is a wooden box (fig. 510) 11 feet 6 inches to 13 feet ($3^{\cdot m}50$ to 4 metres) long, and 20 inches ($0^{\cdot m}50$) wide and deep; the bottom has a slope of about 1 in 12.

The lower end has a number of holes *aa* at different heights, and a shelf at the upper end receives the ore to be concentrated. Lastly, a stream of clean water is supplied for diluting the ore.

The operation is conducted in the following manner:

The charge having been placed upon the shelf, the workman throws the stuff little by little on to the head; the stream dilutes it, and tends to carry it down the inclined plane; but the workman is continually dragging it back towards the head by means of a short-handled rake, which he draws over the surface of the deposit.

The following is the effect obtained:

As the raking is constantly bringing back the stuff into a state of suspension the fine light particles are eventually carried off, and passing through the holes, or finally over the end, fall into the launder *p*, and flow on into the slime-pits. The more or less coarse sand, on the contrary, which the current has not strength enough to carry off, remains in the box, and undergoes a separation by density, the richer stuff settling at the head, and the poorer at the tail.

In order to render the work regular, as the thickness of the deposit increases, the workman stops up the holes *aa* one after the other, and lets the water gradually rise. At the end of about ¾ hour the operation is complete, and the deposit in the box is about 16 inches (40 cm.) deep at the head, and 10 inches (25 cm.) at the tail. The workman then takes out the plugs and lets the water run off, and divides the mass into three vertical slices at right angles to the axis of the buddle, each slice being of a different degree of richness. The quantity of water consumed is about 110 gallons (half a cubic metre).

(**693**) The results of the operation as it was formerly practised in the Hartz, where this apparatus has been most carefully studied, were somewhat complex. The buddles were generally arranged in groups of three, and the products of each were treated either in the same or in the next buddle, until they were sufficiently concentrated to be put aside and sent to the smelter, or were rendered sufficiently poor to be finally thrown away.

The governing idea in these operations was, as we have already seen, to divide the stuff into the following products:

1. A richer concentrate.
2. A product of the same richness as the original stuff.
3. A poorer product.

If convenient, each of these products was added to similar kinds of stuff obtained by similar operations in other buddles.

The rich concentrate was treated again once, or more often, and then finally sent to the smelter.

The poor stuff was treated again, and finally thrown away.

The intermediate product was most commonly treated again in the same buddle, or a similar one; but the operation was naturally more difficult, and it would have been better to have crushed the stuff finer beforehand, as is usually done nowadays.

Poor sand from the German buddle was treated by passing it over a *canvas table* (*Plannenheerd*), an apparatus which may still be seen occasionally.*

This complex apparatus, which we will describe very summarily,

* Blanket-strakes or blanket-tables are used at some gold mines.—*Translators.*

but which must not be passed over entirely, consisted of the following parts:

1. A cleansing box.
2. A step table.
3. A canvas table.
4. A slime pit.

The two first contrivances caught the sand, whilst the principal use of the canvas was to arrest any thin flat particles by the roughness of its surface.

(**694**) As is well known, a dressing machine may be said to improve in proportion as it concentrates more quickly, makes less mixed ore, and separates more rapidly all that is really barren and worthless.

Judged by this standard, the German buddle, which is the primitive type of dressing machines for sand, is very imperfect. Independently of the fact that the concentration is always very incomplete, the stuff has to be handled over and over again, and this renders the dressing expensive and very troublesome.

The principal modification that has been introduced for remedying these defects consists in replacing the work of the rake by longitudinal shakes imparted to the table.

The *percussion table* (fig. 511), the embodiment of this improvement, is still employed at some German works. It consists of a table made of wood or strong sheet iron, with an upright edge on three sides, hung by chains at its four corners. The two chains at the head are always of the same length, whilst those at the foot can be wound up round an axle, so as to alter the slope.

The table suspended in this fashion receives blows from cams acting through a rod, which is drawn back sharply as soon as it has struck the blow. Following this main blow are a series of secondary blows, because the table on returning to its original position strikes against a horizontal beam, the elasticity of which sends it back several times before a fresh stroke from a cam gives it a new impulse.

The principle of the percussion table, which does tolerably good work when the particles are not fine enough to become

plastic, depends therefore upon the inertia of the particles. This inertia tends to make the particles go up the table both during the forward stroke, and more especially during the back stroke, whilst the vibrations help to destroy the cohesion between the particles and the current of water washes them.

The stuff to be treated is thrown into a box, and water is turned on. The stuff is stirred up by a wheel with blades on it, and the muddy water runs down by a launder on to a headboard, with little pieces of wood arranged along two slanting lines, which compel the stream to spread itself evenly over the whole width of the table. The products of the operation are divided almost in the same way as in the German buddle.

It would be necessary to enlarge upon sundry interesting details, were it not for the fact that, in spite of the favour with which the percussion table was regarded formerly, its use is gradually dying out. These details are:

1. The nature of the surface of the table, which ought to be as smooth as possible.
2. Its slope.
3. Its tension, measured by the angle made by the head chains with the vertical.
4. The intensity of the blow.
5. Its length.
6. The number of main blows in a given time.
7. The number of secondary blows for each main blow.
8. The quantity of water.

But although we have described the percussion table, as it is necessary to have some idea of what it was, and although we have enumerated the causes which tend to influence its work, we consider that it would be useless to dwell upon it further, since it is probable that no new table of this kind will be erected in well-designed dressing establishments, excepting where a prejudice in its favour still exists.

(695) This is not the case with the *round buddle*—a machine employed for the same purpose, but very different in its arrangement, and much more economical in its use.

The round buddle, which was invented and has undergone various improvements in England, still enjoys very great favour in that country, and has even been adopted at some Continental works. It consists essentially of a cylindrical pit from 11 feet 6 inches to 20 or 23 feet ($3^{\cdot m}5$ to 6 or 7 metres) in diameter, the bottom of which is made in the form of a very flat cone, down which flows the stream of water carrying the ore in suspension.

According as the stream runs towards the centre or towards the circumference, we get two different kinds of buddle:

1. The convex round buddle, with the flow from the centre towards the circumference.

2. The concave round buddle, with the flow from the circumference towards the centre.

The former, which is shown by Figure 512, is the older shape. The stuff to be treated is brought by a wooden launder to the centre, where it falls into a basin, which is made to revolve by bevel gear. This rotation ensures an even distribution, as the stuff drops on to the upright cone* and runs down over the bottom of the buddle, or over the surface of the deposit already formed, and becomes classified according to specific gravity. The effect produced by raking or by percussion in the preceding machines is here obtained by means of little brushes or strips of canvas, which can be raised at pleasure to suit the thickness of the deposit. They are attached to arms carried by the distributing basin and revolve with it, constantly rubbing the surface of the deposit gently, and assisting the washing by thus bringing the stuff into suspension again; at the same time they prevent the formation of gutters, which would certainly make their appearance, if it were not for this contrivance, and have a very injurious effect on the process.

In the meanwhile the slimy water escapes at the tail end by openings provided around the circumference and is led into slime-pits.

The arrangement of the more recent concave round buddle

* This small cone is replaced in many cases by a broad truncated cone 6 to 10 feet in diameter. See "On Dressing Tin Ores," by W. TEAGUE, jun., *Proc. Mining Inst. Cornwall*, vol. i. No. 3 (Truro, 1877); and "On the Mechanical Appliances used for Dressing Tin and Copper Ores in Cornwall," by H. T. FERGUSON, *Proc. Inst. Mech. Eng.*, 1873, plate 41. Birmingham, 1873.—*Translators.*

is precisely the reverse of that just described. The orey stream is conveyed by a revolving radial launder to the circumference of the buddle, and runs down over the bottom. The slimy water escapes through suitable holes at various heights in a cast-iron cylindrical centre-piece.*

(696) These buddles are generally used simply for preparatory work, and when confined to this function afford fairly good and comparatively economical results. A round buddle will treat from 5 to 10 or even 20 tons of stuff in 10 hours. The deposit is divided into annular portions of various degrees of thickness; the best only goes to the finishing machines, the rest is washed again in the same buddles.

The quantity of water consumed is from 8 to 11 gallons (40 to 50 litres), or from 33 to 35 gallons (150 to 160 litres), per minute, according as the buddle is convex or concave.

Comparing them with the German buddle, we may make the following observations:

1. As the feed is circular, the equivalent layers are concentric instead of being in slices perpendicular to the axis of the oblong box. They are therefore removed in parallel zones or rings.

2. The work of the rake is replaced by that of the brushes or strips of canvas, evidently less powerful, but not requiring the constant presence of a workman.

Naturally a great economy of labour is thus obtained; but, *per contra*, the work is perhaps scarcely as clean as in the hand machine, and furthermore, if the round buddle is to be worked properly, it is necessary to classify the sand carefully and free it entirely from slime.

In neither case, however, are the results complete; in other words, several successive operations are generally required for obtaining a finished product. Furthermore, we must remark that the slope of the surface upon which the deposit is formed is continually changing as the work progresses. This is evidently bad, as it alters the velocity of the stream, and naturally causes

* For figure see Mr. Teague's paper "On Dressing Tin Ores." *Op. cit.*—*Translators.*

an irregularity in the place where particles of the same degree of richness are deposited. The result of this is, that when the stuff is dug out, either in perpendicular slices in the hand buddle, or concentric rings in the round buddle, the upper part of the slice or ring will be richer than the lower part, because it has been deposited upon a steeper surface.

Lastly, any inequalities in the feed, or any gutters in the deposit, which may be formed by accident, have a serious disturbing effect upon the results, which renders the round buddle a somewhat imperfect concentrator.

(697) If we compare the concave and convex round buddles one with the other, we also find marked differences.

In the convex form the water has a greater velocity near the centre, but its speed is slackened towards the circumference. The result of this is, that the head is less sharply defined, because the rich particles may easily be caught by eddies and carried further down along the bed before settling. On the other hand, very few of the rich grains mixed with the poor stuff will be lost, because the current has not force enough to carry them off.

In the concave round buddle, on the contrary, the stuff is fed on at the circumference, and starts with a comparatively slow speed, allowing the rich particles to settle at once. We therefore get a narrow and sharply-defined head; but, on the other hand, if any rich particles are accidentally carried down a little, they cannot be stopped, because the stream increases in strength as it approaches the centre.

As a cure for this evil great care is taken, it is true, to collect the outflowing slime in pits; but this is a very poor remedy. However, as the concave round buddle naturally gets through more stuff in a given time, there is an economy of time and labour, which tends to make it preferred in England, in spite of the losses which it occasions.

(698) We have just said that the round buddle is essentially a machine for making a preliminary concentration, and therefore

the final treatment of the enriched sand must be carried on by other means.

The principal types of machines for this purpose employed nowadays are:

1. In England the *keeve*, which necessarily requires the preliminary treatment of the stuff in a round buddle.

2. On the Continent the Hartz jigger, which can readily dispense with the preliminary buddling, but needs a very exact classification by size.

The *keeve* or *dolly-tub* (fig. 513) is a vat in the form of a truncated cone, with the sides only slightly inclined inwards, standing with the smaller end on the ground. It is made of wood, and is about 2 feet 7 inches (0·^{m}80) high, and at most 3 feet 3 inches to 3 feet 7 inches (1m. to 1^{m}. 10) in diameter. It is provided with a stirrer composed of two blades on a vertical axis, by means of which the liquid in the tub may be thoroughly agitated (*tossed*, Cornwall).

The concentration requires two distinct operations—*tossing* and *packing*.

The keeve is half filled with water, and the stirrer is set going, while the charge is shovelled in little by little, care being taken to throw it towards the side of the tub. As soon as the charging, which requires very little time, is finished, that is to say, when the level of the water is within 3 or 3½ inches (7 or 8 cm.) of the top, the stirrer is taken out.

The *packing* consists in striking light blows on the edge of the keeve, so as to assist the separation.

The blows are struck with a hammer or an iron bar, either by hand or mechanically.* They have the effect of packing the stuff together, as the vibrations tend to make the heavy particles penetrate into the interstices, whilst the lighter ones are forced to rise again. The packing lasts about three quarters of an hour. When it is finished, there is nothing to do but to clear out the keeve. The water is first baled out with a pail on a handle, and what remains is got out by a scoop or a shovel. If necessary a

* See plate in Mr. Teague's paper "On Dressing Tin Ores," *Proc. Mining Inst. Cornwall*, vol. i. No. 3. Truro, 1877.—*Translators.*

little pit may be dug out in the deposit; the water collects in it, and can easily be scooped out.

This being done, the deposit is scraped out. It is usually divided into two parts—the top, which is still mixed and requires to be buddled again, and the bottom, which is sufficiently concentrated.

(699) The *Hartz jigs* (fig. 514), which belong to the category of continuous jigs, differ from those already described by the discharge taking place all over the sieve bottom, and not merely through a few openings in the sieve or in the side.

All that is necessary is that the meshes of the sieve should be larger than the stuff treated, and that a layer of coarse heavy particles should be spread on the sieve to prevent too much ore from passing through.

The operation of jigging then goes on as follows:

The stuff is fed in regularly at the head of the jigger, and the strokes of the piston raise both it and the *bed* of heavy particles. The heaviest grains of ore find their way, during the downstroke, between the interstices of the *bed*, gradually descend through it, and finally come to the sieve and fall through. The light constituents of the ore cannot go down, and are carried over the end partition on to the next sieve, or are finally washed away, by the horizontal current due to the continuous supply of water.

We see, therefore, that a one-sieve jigger gives only two products, and that with an ore which is at all complex, it will be necessary to have a jigger with several sieves. In practice there are generally three or four.

(700) As regards the machine itself, we must notice the following points:

1. The cylindrical form of the *hutch*, which appears to be decidedly the best for preventing injurious effects, already pointed out more than once, caused by the irregular action of the water on the stuff lying on the sieve.

2. The manner of imparting the reciprocating motion to the piston, which is given, not by the differential link as in the former

jiggers, but by an excentric on account of the rapidity and shortness of the stroke.

3. The device for altering the length of the stroke; instead of the excentric being keyed directly to the shaft, it is carried by a second excentric attached to the shaft, so that the total excentricity may be made to vary from the sum to the difference of the partial excentricities (fig. 514*c*).

4. The arrangement adopted for discharging the ore. An outlet hole is made in the bottom of the hutch, which is either generally kept shut, and then opened occasionally, or is kept slightly open so as to let the concentrate pass out continuously without too great a loss of water. The discharge valve is regulated by a rod worked by a handle; a simpler plan is to have a discharge pipe fixed in the side, and stop it up with a wooden plug. But whatever kind of outlet is adopted, and whether the discharge is continuous or discontinuous, there is always a considerable loss of water, which has to to be made up each time by a fresh supply.

5. Lastly, the nature of the sieves. They are generally made of iron or brass wire, and the meshes are considerably larger than the grains of ore treated.

(701) With reference to the manner of regulating the work we must note:

1. The number and length of the strokes, important elements for successful working, which vary with the size of the stuff treated. The number of strokes per minute is from 60 to 80 with coarse sand of $\frac{1}{12}$ inch (2 mm.) in diameter, and 200, 300, and even, as has been tried with success, 400 with very fine sand approaching a slime. The length of stroke varies under the same conditions from $\frac{3}{8}$ inch (1 cm.) to $\frac{1}{5}$ inch (5 mm.), and in the case of very fine almost impalpable sand, the stroke may be diminished till it becomes a mere tremor.

2. The nature and the depth of the bed placed upon the sieve. The depth must vary with the degree of concentration, and it can only be regulated by actual experiments. It may be stated, however, that it usually does not exceed $\frac{4}{5}$ inch (2 cm.), and that it must increase with the size of the stuff, and with the degree of concentration required.

The bed must be made of particles not exceeding in density, at all events to any great extent, the product which it is proposed to collect through the sieve. The best plan is certainly to make it of particles of the same mineral as the concentrate sought for.

Thus, on the sieves for separating galena, or a rich mixture, the bed will be made of grains of galena, and of grains of blende on the sieve separating blende, &c.

3. The mode of feeding, as regularity of feed is an essential condition of good working; we shall see further on how the feeding is generally done.

4. Lastly, the quantity of water. This is generally somewhat large, and may amount to as much as 73 gallons ($\frac{1}{3}$ cubic metre) per minute.

(702) The results obtained with the Hartz jigger are very good; the quantity treated may reach 5 to 10 tons per day of ten hours.

The nature of the concentrates varies according to circumstances, the nature of the ore, &c. In a case which is very common in practice, and which we have therefore often quoted, viz., that of an ore containing galena and blende, the first compartment of a four-sieve jigger will collect galena, the next a mixture of galena and blende, then blende, then blende and waste, and finally there will be waste which will be thrown away. The yield of the galena may be as much as 72 per cent., and that of the blende 50 per cent.; the mixtures (*dradge*) are generally treated again in the same machines after having been re-crushed.

It sometimes happens, however, that when an ore easily breaks into thin plates, such as some cleavable galena and blende, and carbonate of lead, these flat particles are carried away by the waste over the end of the sieve on account of the strength of the current occasioned by the great quantity of water which has to be supplied to the jigger. In a case of this kind it will be well to place an upward-current separator at the end of the jgger, and regulate it so that the grains of waste fall to the bottom, whilst the thin plates are carried over and made to settle in slime pits.

However, it may be stated in a general way that the Hartz jigger may be employed for concentrating any kind of ore, and

that for enriching even very fine sand it is the simplest and most economical machine yet invented; that it requires the least amount of labour, and that it at once furnishes in the case of the most complex ores two finished products, a result not attainable with any other machine.

(703) It is true that it will not work well unless the feed is perfectly regular; but this is neither a great defect nor a great difficulty.

We have already seen, when describing the jiggers for gravel ore, the various simple devices which may be employed for feeding. It will perhaps be advantageous to use the screw feeder for very coarse sand; but whenever the stuff is at all smaller than $\frac{1}{25}$ inch (1 mm.) it is better not to let it settle, but to conduct the orey stream direct from the classifier to the concentrators. If necessary a small centrifugal pump may be employed to raise it.

Figure 515 represents the mode of distribution at Steinenbrück. The water carrying the ore and waste in suspension is raised by a little pump (P) to the level of the classifier, placed at a good height above the floor of the works; and the classifier makes eight categories of sand and slime, which are conveyed separately by pipes to the concentrating machines—in this case six Hartz jiggers and two rotating tables.

We see how simple and regular this method of feeding is. It is one which should be adopted generally as being easier and more economical than any other, unless under some very exceptional circumstances.

However, if necessary, under certain special circumstances, Huet and Geyler's centrifugal feeder might be used. In this machine (fig. 516) a horizontal wheel turning with rapidity sucks up the orey water from the bottom of a conical vessel and conveys it to the jiggers, whilst the excess of water with the light particles runs over the top into a lateral discharge-pipe, the opening into which is placed at the top.

This machine is evidently a *classifier* as well as a *feeder*; consequently there may be special reasons for employing it under certain circumstances.

(704) As a supplement both to the account of jiggers and to paragraph 672, where we spoke of the sizing by the dry way formerly tried at Engis, we must now describe an *air jig*, employed for some time past in the United States for fine stuff, such as sand and dust, which appears to be gaining a certain amount of favour.

It owes its birth to the idea that water, on account of its high specific gravity and capillary effects, is a very defective separating medium for ores which tend to assume the form of thin plates, and consequently to float on its surface. This result is specially injurious in a case of this kind, because when such ores are crushed the dust is richer than the coarser particles, on account of the valuable mineral being softer than the veinstone.

In order to avoid such a drawback, ores containing the tellurides of gold, which are very brittle and cannot be concentrated by the ordinary appliances, because the fine particles remain in suspension or float on the surface, have been subjected in Colorado, by way of experiment, to a special treatment. The ore was crushed as fine as possible, and put into tubs of water provided with stirrers, so as to bring the tellurides thoroughly into suspension, and then the liquid was decanted.

The ore was thus divided into two distinct portions—the deposit freed from the fine dust, which was further treated by the ordinary method; and the decanted liquid. This was evaporated, and left a rich residue.

It appears that this curious method, which evidently is only suited for rich ore, gave sufficiently encouraging results to be continued.

(705) It is as a remedy for this same drawback, but in a totally different way, that the air jig has been tried.

This machine, as constructed by Mr. Krom (fig. 517), consists essentially of the following parts: A charging-hopper; a sieve, upon which the separation takes place; a reservoir or compartment below it, in which the ore is retained for more or less time; and lastly, a fan, the rapid strokes of which replace the action of the piston.

The charging-hopper has nothing special about it. A little

hatch, which can be raised or lowered, enables the amount of feed to be varied at pleasure; whilst a movable edge-piece regulates the depth of the ore upon the sieve.

The sieve is composed of tubes of wire-cloth, open below and at one end, placed side by side, with interspaces varying according to the size of the ore treated, and diminishing as it becomes finer. They open into the fan-box.

The reservoir is partly closed below by a fluted roller, which can be made to revolve more or less rapidly, and so effect the discharge at any desired speed. If we reflect that the unconcentrated stuff is resting by means of the interspaces between the sieve-tubes upon the concentrated ore filling the reservoir, and follows it in its descent, it will be evident that the movement of the roller governs the rate at which the stuff passes through the jig.

Lastly, the fan; this is a simple piece of sheet-iron with india-rubber valves, which is made to oscillate about an axis at one end in the following manner:

A driving-wheel with six cams pushes out a lever, and a spiral spring brings it back to its original position as soon as it is free. The wheel is made to revolve rapidly, and for every revolution the lever, and consequently the fan which is borne by the same axis, will make six complete oscillations.

(706) The course of the operation is very simple. The ore is resting upon the wire-gauze tubes and through their interspaces upon the concentrate in the reservoir. Each up-stroke of the fan sends a short puff of air into the tubes, which passes through the gauze at the top and sides, raises the layer of ore, and so effects the separation.

In proportion as the reservoir discharges its contents, the concentrate sinks down, whilst the dust and the waste pass over edge and are thrown away.

We must notice the following ingenious details of the machine:

1. The arrangement of the sieve, which allows the concentrate to be discharged rapidly, and obviates all chance of obstruction, as the tubes are open below.

2. The mechanical contrivance employed for moving the fan.

It is very simple, and realizes as far as is possible for so rapid a movement the conditions of a *sharp start* and *gradual return*, the sharpness of the stroke being moreover independent of the speed of the machine.

3. Lastly, the automatic discharge roller worked by a ratchet-wheel actuated by the driving-wheel. Its speed is consequently in proportion to the number of oscillations, and therefore the *quantity concentrated and the quantity discharged increase or diminish together*.

The number of strokes is regulated when the machine is started; but even if the quantity or quality of the ore were to vary, no very great harm would ensue, and there would be no loss, because the air has not power enough to raise and stir up any particles which are decidedly heavier than those for which the jig has been set.

Upon the whole this machine, which is remarkable both for its general arrangement and for the details of its construction, appears to have given very good results, especially when the ore has been thoroughly well classified beforehand, although this is not absolutely indispensable. It is small, easily moved about, and may in any case be employed with advantage in hot countries, where water is more or less scarce. With $\frac{1}{8}$ horse power to drive it, it gives three to four hundred strokes per minute, and will treat about $\frac{1}{2}$ ton per hour; but, as is evident, it only furnishes one kind of concentrate, which somewhat limits its usefulness, and will prevent its being employed at most mines where the veins have a somewhat complex composition, which is the case at many of those on the Continent.

3. Treatment of the Slime.

(707) We have now finally to explain the methods of treating the very fine stuff forming a more or less impalpable mud, which comes from the last of a series of pointed-boxes, or from upward-current classifiers, or from slime-pits.

The concentration of these substances always presents somewhat considerable difficulties, both on account of their very minute size and their plasticity. Their fineness renders them liable to be

carried away by the liquid in which they are suspended, and their plasticity interferes with the results expected theoretically, by preventing that complete disaggregation which is necessary for obtaining a tolerably sharp classification.

The consequence of this state of things was that for a long time slimes below a certain degree of richness had to be thrown away, because the cost of concentration was much too high compared with the indifferent yield obtained in practice. Accordingly the immense piles of slime which have been found at some old dressing-floors have been often treated over again with profit, by means of the comparatively new and greatly improved machinery, with which the art of dressing has been endowed.

For many centuries the *plane table* or *frame* was the only machine employed. In form and in the manner of using it it presented a certain analogy with the German buddle employed for sand; but it was less inclined, and there was much less raking. The stuff was fed on in the form of a thin orey stream, which ran down over the surface of the frame, and allowed the heavier particles to settle in the order of their specific gravities.

When the frame was covered, the deposit was divided like that of the hand-buddle into several parts, and these were *framed* over again, until at last a *head* was obtained with a sufficient degree of concentration.

The frame is still used in England,* but with this difference, that the operation is regulated so as to obtain a more concentrated product, which is washed off suddenly by a strong stream of water into a settling-pit.

The first attempt at improvement consisted in imparting blows to the frame; but as the number of blows had to increase, and their strength to diminish, with the fineness of the stuff, it finally resulted that they had no effect, for the particles became

* For figures of the Cornish frame see "On the methods generally adopted in Cornwall in Dressing Tin and Copper Ores," by J. Henderson, *Proc. Inst. C. E.* vol. xvii. Plate 17. London, 1857–58; "On the mechanical appliances used for Dressing Tin and Copper Ores in Cornwall," by H. T. Ferguson, *Proc. Inst. Mech. Eng.*, 1873, Plates 48, 49. Birmingham, 1873; "On Dressing Tin Ores," by W. Teague, junior, *Proc. Min. Inst. Cornwall*, vol. i. No. 3. Truro, 1877.—*Translators.*

packed together instead of being separated according to specific gravity, and this device failed therefore to secure the object aimed at.

It thus became necessary to have recourse to entirely new methods, which are carried into practice by a large variety of machines, the most important of which are the rotating frames or tables and the side-blow percussion tables or Rittinger tables, so called from the eminent Austrian engineer who invented them.

(708) The rotating tables, which are much used in the dressing-floors on the banks of the Rhine, consist of a very flat cone, either concave or convex, like the round buddles already described, which is fixed to a vertical axis around which it is made to revolve uniformly.

We will take for example the convex table (fig. 518). The slime is fed on continuously at the apex, and runs down the slope, moving with the cone of course. The minerals in suspension settle at a greater or less distance down the slope according to their specific gravities, and as the table revolves the deposit is brought successively under three or four pipes of unequal lengths, fixed a little above the table; these are perforated with a number of holes, and shoot out jets of clean water, which wash the deposit, and force it to go down the inclined plane formed by the surface of the cone.

Lastly, the two or three categories of ore, on arriving at the periphery, fall into special compartments of a circumferential launder. The portion of the table which has passed the last pipe has been washed clean, and is ready to receive a fresh supply of slime. This description gives a very fair idea of the simple and rapid manner in which the machine works.

The concave table differs only with regard to the points of supply and discharge. The slime is fed on at a point of the circumference, and the classified products are collected and escape at the centre.

(709) More or less important differences may be noticed among the numerous rotating tables employed in Germany.

In the first place their general arrangement varies, and this is generally dependent upon their shape, whether convex or concave.

The convex tables are generally set up singly, and consequently receive the slime directly, and distribute the classified products into various catch-pits placed around them.

A concave table, on the contrary, is generally coupled to a convex one, and is placed either above it or at one side. Like the concave round buddle, it commences by making a very sharp concentration at the circumference; but as the current becomes stronger towards the centre a somewhat considerable number of richer particles are swept away, which it is the very object of the frame to catch.

This juxtaposition of two tables involves a certain complication in erection which it is better to avoid, since the advantage to be gained by it is not important. It may be said also, as a general rule, that if rotating frames are to be adopted, it is best to be content with the ordinary convex form without resorting to a cumbrous and complicated combination.

(710) It is principally in their mode of construction that rotating frames offer the greatest variety.

They are most commonly made of wood. Small radial beams are fixed upon a strong cast-iron centre-piece (fig. 518), and upon these is placed a first flooring of deal. A second covering of beech is then carefully nailed on to it; the planks being arranged radially, and joined accurately, and planed till the surface is perfectly even.

In spite of all the care bestowed upon their construction, wooden tables as a rule soon swell up under the action of the moisture; the joints start, and the wood warps, so that the evenness of the conical surface, a *sine quâ non* for good work, is soon destroyed. Irregular deposits then form in the hollows, and interfere with the separation. This defect can never be remedied entirely even by continual repairs, or by brushes with a backward and forward motion, which bring the deposit into suspension again, and compel the various minerals to go down to their proper positions.

The experiment of constructing the rotating-frames of metal was therefore tried, and has succeeded perfectly.

Fig. 519 represents a cast-iron table of this kind employed at Laurenburg. It is 16 ft. 4 in. (5 metres) in diameter, and, on account of its size, it is made of two halves, firmly bolted together, with the surface carefully turned. The cost of the turning, which must be perfectly regular, because the quality of the work depends upon the uniformity of the slope and evenness of the surface, renders the machine decidedly expensive, but not enough to make one hesitate to adopt it.

(711) It is necessary also to notice several variable elements which may affect the success of the operation. They are as follows:

1. The diameter of the table and its gradient, which depend upon the nature and size of the substances treated. The larger a rotating frame is, the greater the amount of stuff it will treat in a given time, and the poorer and more complex the ore may be. The diameter may be from 8 to 12 or 16 feet ($2.^{m}50$ to 4 or 5 metres). The inclination depends upon the fineness of the slimes and the amount of clay they contain, which renders them more or less sticky; but the effect of the slope can be easily corrected by varying the amount of clean water. It is generally from 5° to 6°.

2. The number of revolutions per minute. The speed is always slow, and must be perfectly regular. It varies between limits which can scarcely be laid down precisely, and may be from ½ to 1 revolution per minute. The maximum, which is left to the practical common sense of the engineer, is determined by the time required for the ore to settle and be washed off.

3. The quantity of water. This depends upon the same influences, and varies from 20 to 60, 90, or even 100 gallons (100 to 300, 400, or even 500 litres) per minute.

Supposing all these elements to be regulated in the best possible manner, the yield will still vary according to the quality of the stuff and the amount of concentration required.

The quantity treated may be from 2 to 3 tons for small tables, and from 10 to 15 or even 20 tons for cast-iron tables; and the

amount of work will vary moreover very greatly with the more or less satisfactory state of the surface, which has a great influence upon the results. The quantity of finished products will always be relatively small. The tables are essentially machines for a preliminary concentration; and if the ore is somewhat poor, it will have to be treated over again twice. Even then, as a rule, the concentrate will not be very rich, and in the case of a mixture of galena and blende will rarely yield more than 50 per cent. of lead, and will still contain a notable quantity of zinc, the injurious effect of which in lead smelting is well known.

Consequently if it is thought advisable to obtain a higher yield —that is to say, a perfectly clean separation of the ore into its constituent minerals—the stuff must be treated finally upon Rittinger's *side-blow percussion tables.*

(712) These machines consist of a plane rectangular surface, perfectly smooth, slightly inclined, and subjected to rapid blows on one side.

We must imagine that the stuff is fed on at one of the two upper corners of the table, over which a uniform sheet of clean water is flowing continually, and that on the opposite side there is a bumping-piece, against which the table strikes suddenly. The particles possess the same lateral velocity as the machine, and will continue their transverse motion in virtue of their inertia, whilst at the same time they will be carried down the table by the descending stream of water.

But as the effect of inertia is proportionately much greater upon the heavy particles than upon the light ones, the result is that after a few blows the minerals classify themselves upon the table and make their way downwards, under the influence of the stream of water, in the form of more or less regular bands. These bands or stripes assume a more or less parabolic shape from the upper corner, where the stuff is fed on, to the lower edge of the table. The points of intersection with this edge approach the bumping side in proportion as the specific gravities are greater.

The conditions which we have just set forth have been carried out in practice in the following manner (Figure 520):

The machine is generally double; that is to say, it consists of two tables placed side by side and moving simultaneously. This arrangement is by no means indispensable, but it economizes power and gearing. The tables are fixed upon a strong rectangular frame hung at its corners from four chains, which can be lengthened or shortened at pleasure. The frame is provided with two cross-timbers, which butt against the fixed bumping-piece. The latter is very firmly stayed.

Cams on a revolving shaft act upon a rigid rod, which pushes the tables from their position at rest, to which they are brought back by a strong spring arranged for the purpose, as soon as the cam has left the rod. It is at the end of this return movement that the cross-beams strike the bumping-block.

(**713**) In the actual construction of the machine, we must notice:

1. The arrangement both of the moving and of the fixed frame. The latter, as already stated, must be made particularly firm on account of the number of rapid blows to which it is subjected. Its foundations must be made with the greatest care, and the bumping-block must be tightly connected with it, so that the blows may not stir it, as would certainly happen if this precaution were not taken.

2. The nature of the springs, which have to bring back the table sharply to its position at rest. These springs are sometimes made of india-rubber, more often of steel, but most frequently they are mere strips of wood arranged like carriage-springs. Wooden springs have the advantage of being simple and economical, and of not being affected by rust or variations of temperature.

The power of the springs should increase with the number of blows, so that the frame may have struck the bumping-block before the next cam begins to push it out.

3. The nature of the surface of the table, upon which the quality of the work depends. The surface ought to be perfectly plane and smooth, so that the particles may move with entire freedom, in spite of their fineness. Wood, which

was tried at first, did not answer thoroughly; it soon warped, and became rough, which had an injurious effect upon the separation.

The following substances have been tried:

Sheet-iron, which was fixed upon the wood by a number of countersunk screws; but it was impossible to prevent buckling, on account of the unequal expansion of the metal and of the wood upon which it was mounted.

Planed cast-iron. This had the defect of rusting, of being somewhat brittle, and of rendering the machine very heavy.

Glass, which was soon given up on account of its brittleness.

Lastly, *stone*, and especially common marble and slate. Slabs of these materials, of sufficient size and smoothness, can easily be obtained, and they are comparatively light. It seems, therefore, advisable to adopt them in all cases, on account of the advantages due to their not being affected by moisture or changes of temperature.

(714) The operation is carried on in the following manner:

The stuff, which has been perfectly freed from slime and properly sized, arrives at the upper right hand corner of the table, upon a little head-board, with two slanting rows of wooden buttons. As soon as it falls upon the table it is subjected to the action of the blows, and of a thin sheet of clean water. The particles soon separate; the heavy ones go to the left, and the lighter ones, which are more easily carried off by the current, follow a more direct course, approaching the line of greatest slope. The separation is effected sufficiently quickly to enable one to perceive, even at the top, the bands or stripes of different minerals, which will be blue, greenish, and yellow, if we are dealing for instance with galena, pyrites, and blende.

The separation is effected so easily and sharply, that any desired quality of ore can be cut off and made to fall into the tank below, by means of the wooden pointers fastened upon pins at the end of the table. In the commonest case, that of blende and galena, the products obtained will be galena fit for smelting, a mixture of blende and a little galena, blende, and finally waste. The two

intermediate products will be passed over the table again separately, and will furnish rich blende.

Lastly, we must notice the little transverse blade fixed obliquely across each table. It is placed there for the purpose of wetting and submerging little floating particles of galena, which otherwise might swim away altogether. These blades are very useful, and are indeed indispensable with some kinds of ores.

(715) The tables which we have just described may be employed for treating the finest sands and the slimes. However, with the very finest and absolutely impalpable slimes, especially if they are clayey, the tables become somewhat *greasy;* that is to say, the stuff sticks to any roughnesses of the surface, however slight they may be, and no longer descends in a continuous manner. In a case of this kind we must return to the rotating tables, as the jets of water can be made to play upon the ore with any amount of force required for washing it off.

The size, inclination, &c., of the tables depend upon the fineness of the ore to be treated. We may have a length of 8 to 10 feet ($2.^{m}5$ to $3.^{m}$), a width of 5 feet to 5 feet 6 inches ($1.^{m}5$ to $1.^{m}7$), and a gradient of 3° to 6°. The number of blows is from 200 to 300, and the quantity of water from 2 to 4 gallons (10 to 20 litres) per minute, according to the fineness of the ore.

Lastly, the amount treated in a day may be from 3 to 4 or even 5 to 6 tons; but the separation is perfectly sharp at once, and we are able to obtain galena with 75, 78, and even 80 per cent. in the first operation, whilst all the blende is separated in the second.

(716) The two *fundamental* machines used for treating slimes on the Continent may be compared with each other in the following terms:

The rotating table is somewhat cumbersome and does not effect a good separation, inasmuch as the galena always retains a large proportion of blende, which is not only lost as such, but is also very injurious in smelting the lead ore. However, a well-arranged

large cast-iron table will treat a great deal of stuff. The rotating table may therefore be employed with advantage when speed is an object, or when we are dealing with an ore which is easily dressed, and which need not be washed thoroughly clean.

On the other hand Rittinger's percussion-table is a machine doing delicate work, which effects an excellent and complete separation between the different constituent minerals, sometimes after one operation, and in any case after two. Under these circumstances it often seems to be almost indispensable, because it is the only machine capable of treating complex ores; but it has two defects—it cannot treat much stuff in a day, and it costs a good deal for repairs.

Both machines also require to be fed with the utmost regularity, an operation that may be effected in the manner described in paragraph 703, for sands.

(717) Whilst the desire of converting the very intermittent work of the old tables into a continuous operation, and to perfect their results, led to the invention on the Continent of rotating tables and side-blow percussion-tables, the same end was being attained in England by *Brunton's frame.*

The principle of this machine consists in feeding the ore in suspension in water on to an endless canvas belt, of which the upper part is slightly inclined, and there subjecting it to the action of a stream of clear water. The waste is washed off, whilst the rich part hangs on, so to say, to the roughness of the canvas, is carried along as the belt moves, and is finally discharged at the upper end.

The first modification of this machine consisted in giving it end-blows like those applied to the percussion-table which succeeded the buddle; but both this and the original Brunton's frame have been almost entirely abandoned.

It then happened that the principle of giving side-blows, like those of Rittinger's table, led to the idea of applying them to the endless cloths. The latest modification adopted by Mr. Frue, and known as the *Frue vanning machine,* appears to be meeting with great favour in North America, and is even beginning to be introduced in England.

(718) It consists (fig. 521) of a large fixed framework, carrying inside it a movable frame provided with rollers, upon which runs the endless belt.

The movable frame, which has an inclination of 3 to 5 per cent., according to the nature of the ore, has a reciprocating motion sideways imparted to it by means of cranks, the stroke being 1¼ to 1½ inch (3 to 4 centimetres). At the same time the endless belt is made to revolve by means of a drum at one end. This belt is 4 feet wide and 27 feet long altogether, the upper surface being 12 feet long. It is made of india-rubber cloth, provided with raised edges to prevent the stuff from escaping sideways.

The ore in suspension in water arrives by a launder at the head, where it is subjected to the action of an independent stream of clear water, and passing down the table runs off into another launder at the tail.

It will now be easy to understand how the machine works.

The fine particles of mineral descend the belt little by little, being washed down by the current, and being kept in suspension by gentle shakes; but the amount of clear water is so regulated that whilst the waste is gradually washed away, the heavier particles are drawn up by the belt and pass the little jets of water at the head, which are about one or two inches apart. A portion of the concentrate falls into the tank below as soon as it has passed the last roller, and the rest is washed off when the belt dips into the water in passing over the larger drum.

As we have merely wished to explain the principle upon which the machine works, we do not propose to dilate upon the various details of construction, which have all been carefully arranged, and render the regulation of the washing a matter of great ease. We may however notice one detail, because it is a novelty. One of the great defects of similar tables has been the wear of the belt caused by the ore passing over it. In the Frue vanner this defect has been remedied by using a solution of india-rubber to form a coating upon the belt, which wears slowly, and can be renewed as often as desired.

A table of this kind will treat 7 to 8 tons of ore in 24 hours, and requires only ⅛ horse-power; one man can attend to four

tables at once. As is the case with all other dressing-machines, the results improve in proportion to the care bestowed upon the sizing; but as the slightly rough and catching nature of the india-rubber surface enables it to retain fine particles readily, whilst the slope of the table, the side-blows and the jets of water at the head all prevent any very large particles from travelling up to the top, it follows that Frue's machine, which appears well adapted for washing any fine ore, may also be applied with success in treating a heavy fine mineral mixed with a relatively light and much coarser veinstuff. This seems to us the characteristic upon which its use will depend.

It was first of all applied to the treatment of tellurides, which are very brittle, and easily reduced to powder; and it has subsequently been employed with success in washing blende, galena, tin ore, and native gold and silver; but it has the defect of being able to treat a binary ore only, or at least to furnish only two products.

CHAPTER XXV.

RÉSUMÉ.—EXAMPLES.—SPECIAL DRESSING OF DIFFERENT ORES AND OF COAL.

§ 1. Résumé—Examples.

(719) The branch of mining known as mechanical preparation or dressing, of which we have just described the principal appliances, has undergone immense changes during the last fifty years.

After having passed through numerous modifications, the dressing of metallic ores, but not that of coal, appears now to have settled down into a limited number of methods, adapted not only to the kinds of ore treated, but also to the wants of the countries in which they were invented. It is impossible, however, to say how long this settled state of things will last.

In a general way, it may be said that the art of dressing depended formerly:

1. In theory, upon two principles admitted at that time without discussion; viz., hand-picking carried to its extreme limits, and the division of the mine stuff into as many classes as there were different ores or different veinstones, with a second subdivision of each of these classes according to richness. Each subdivision was then subjected to a special treatment adapted to its nature.

2. In practice, upon the employment at first of very simple machines, and then of more complicated ones. These machines were always very imperfect, caused great losses of ore, and so warranted the minute preparatory hand-picking of which we have just spoken.

It may be true that this method had the advantage of considerably reducing the loss in dressing, both by withdrawing the stuff as much as possible from the troublesome and imperfect treatment in the rude machines employed formerly, and by obtaining the greatest advantage in washing, on account of the sub-division into different classes; but, on the other hand, it had the drawback of increasing the cost of labour very considerably, and of necessitating the accumulation of piles of half-dressed ore, which temporarily locked up the capital represented by their value.

This mode of working has generally been changed nowadays; and the course taken by the principal improvements has been chiefly marked:

1. In theory, by the employment of successive crushings gradually finer and finer, and by the increased adoption of jigging machines, formerly used for particles not smaller than $\frac{1}{12}$ inch (2 millimetres), but now applied to the treatment of the finest sands, so long as they are not absolutely impalpable.

2. In the construction of the machines, by perfecting all their details, and by substituting metal for wood, which makes it necessary in well-arranged dressing-floors to employ a special fitter, instead of the ordinary carpenter.

3. In actual working, by reducing the amount of manual labour. This has been effected by substituting the stone-breaker for spalling, by adopting improved machines, especially the mechanical piston-jigger in the place of the hand-jigger, revolving screens instead of fixed or shaking sieves, rotating frames or Rittinger's tables instead of the plane tables, by using mechanical contrivances such as elevators, Jacob's ladders, centrifugal pumps, &c., for raising and conveying the stuff on the dressing-floors; and, lastly, by making the action of the machines automatic and continuous.

(720) In the preceding chapter we became acquainted with the machines by means of which these improvements have been realized, and their value is so well recognized that we are almost certain, in visiting any dressing-floors, to find many of them in use.

In France and Germany we shall have:

For crushing:—a stone-breaker, two or three pairs of rolls, and perhaps a few heads of stamps.

For sizing:—gratings, revolving screens, and ascending current classifiers, followed by a series of slime-pits.

For concentrating:—intermittent or continuous jiggers for the gravel, Hartz jiggers for the sands, and machines for dressing slimes, of which there is a greater choice. They are nearly always rotating frames or side-blow percussion-tables.

In England, on the contrary, the use of stamps, the jigger with a moving sieve, the round buddle and the frame, completely changes the conditions of the dressing process, and gives rise to a special *ensemble*, the different details of which have been duly described.

We have discussed the manner in which all these machines work, and their various advantages and defects, and we have now sufficient data for forming an opinion about them. It still remains for us to examine how they may be arranged together, so as to ensure the work being performed in the most economical manner. We will now proceed to point out how this is effected, and afterwards give some numerical data taken from special examples.

(721) If we have to utilize the products extracted from a mine soon after it is started, or during the preliminary exploratory period, when it is still uncertain whether it will pay to work it, it is quite evident that it would be most imprudent to erect dressing machinery of any importance, and that it is better to content one's self with taking the richest stuff only, and treating it in small hand machines. Thus a more or less rough crusher, an intermittent jigger for the gravel, a German buddle for the sands, and a frame for the slimes, will enable a certain amount of concentrated ore to be extracted from the stuff raised from underground, and this will cover part or all of the cost of mining. We must be careful, however, not to throw away and lose the stuff rejected at first, because it will often be rich enough to be worth treating later on, when more perfect machinery is available.

As the workings are gradually developed, the primitive appliances just mentioned may be supplemented by the more expensive and also more effective machinery, which will be required in a complete dressing establishment, such as crushing rolls, revolving screens, continuous jiggers, &c., and these may be worked by steam or water power if necessary.

Lastly, when the future of the mine is fully assured, it will be necessary to think about a complete dressing establishment, provided with all suitable appliances, and arranged so as to work under the best possible conditions. These conditions should be studied with the greatest care, because they are capable of making a very great difference in the profits of the concern.

The first thing will be to decide between the *German type*, adopted in nearly all Continental work, and the *English type*, which has never been introduced there, and probably never will be, because it is based upon entirely different principles, and upon usages somewhat in harmony with the character of the people among whom it had its birth.

(722) The characteristic features of the German type are the extreme care bestowed upon the processes, and the greater or less continuity aimed at, either for one operation considered by itself, or for the passage from one operation to another.

Thus, supposing the dressing-floors to be situated below the mouth of the adit level or the top of the winding shaft, the upper part will be devoted to the crushing machinery and picking tables. The various products will then descend by gravitation to gratings or revolving screens, which size them and distribute them into separate bins, whence they are taken by elevators or inclined wooden launders to the different jiggers appropriated to their treatment. The finest particles, which if left to settle would form a deposit, and could with difficulty be brought into a proper state of suspension again, pass into an ascending current classifier directly, if there is sufficient fall, or if not, they can be lifted by a centrifugal pump. The classifier should be placed high enough to distribute its products (by means, for instance,

of the plan described in figure 515) to the different jiggers, revolving frames, or percussion-tables, by which the concentration is to be effected.

The consequence is that a workman is not required, save for emptying the concentrated products from the hutches into which they have been discharged, and for taking back, if necessary, any intermediate mixed products which have to be passed once more through the same or similar machines. Strictly speaking, all the stuff coming direct from the mine may be crushed, sized, and at least partly concentrated, without being handled by the workmen.*

This method of working has the great advantage of diminishing the cost of labour very considerably; but it is coupled with the drawback of entailing great expense for keeping in repair the Jacob's ladders, elevators, &c., which cannot as a rule be dispensed with. There is also the further great disadvantage, that as the works are erected for a certain class of ore the machinery has to be re-adjusted if the ore happens to alter in quality.

We must also remark, from a different point of view, that the fact of one machine getting out of order may upset the working of all the rest, and this is an additional drawback which should be taken into serious consideration.

In spite of these disadvantages, however, there is no doubt that on the whole the continuous system of dressing is a very decided improvement upon the essentially intermittent system formerly in use, and one which ought to be recommended as a general rule, provided that it is not pushed too far in the details, and that we do not sacrifice the advantages which are always secured by simplicity.

(723) The English method is entirely different, and much ruder. The machines are more imperfect and essentially intermittent, whether considered separately or collectively. The sizing is frequently effected solely by the passage through successive jiggers, and much ore is lost which might be saved.

But to make up for this there is a gain of time; and if the

* This is done at some English dressing works.—*Translators.*

stoping is pushed on with activity, the gain produced by treating an extra quantity of stuff will more than compensate for the loss sustained on the rest.

In other words, there will be a waste of ore; but as the usual object of the mine owner, especially in England, is to realize the greatest amount of profit in a year, without taking any thought for the future, it is evident that there may be an advantage in proceeding thus, and in making less profit per ton, provided the number of tons extracted and dressed is larger.

(724) The radical difference between the two methods is plain. In Germany the object is to dress the ore *well,* in England it is to dress the ore *quickly.*

Whichever method may be adopted, it is necessary first of all, in laying out dressing-floors, to choose the site, which ought to be situated as near as possible to the place where the ore reaches the surface. This consideration, however, must not be allowed to outweigh the advantages which might result from a convenient slope, the proximity of water, &c. The next thing is to calculate the quantity of water and the motive power required. Then the machines must be arranged so as to group together similar operations, and to avoid having to move the stuff about too much, &c. All these points should be examined very closely, and studied with reference both to convenience and economy, which will frequently lead to the same conclusion.

Two special examples, taken from works recently put up or re-arranged in Germany and England, will serve to illustrate how dressing-floors are laid out, and will at the same time explain the manner in which certain special ores are treated.

(725) The first example we shall choose is that of the Castor works, near Cologne, belonging to the Vieille Montagne Company.

The ore treated is a mixture of galena and blende, with spathose iron, iron pyrites, copper pyrites, and carbonate of lead, associated with *grauwacke* as veinstuff. The ore is derived from two distinct lodes, one of which contains on an average 22 per cent. of galena, and 5 to 6 per cent. of blende; the other 24 to 27 per cent. of

blende, and 6 per cent. of galena. The two classes of ore are treated separately, and at different times.

We will suppose that the works are arranged for treating the ore rich in galena.

The ore, in the state of *rocks* or *smalls*, arrives in waggons from the mine upon a high stage (fig. 522), from whence different classes of stuff can be taken to different machines.

The *rocks* are trammed through a long gallery to a stone-breaker, under which is fixed a grating with bars $1\frac{1}{4}$ inch (32^{mm}) apart. This grating catches the large pieces, which are brought back by the same road to the picking-tables; the smaller pieces fall through, pass between two large rolls, are crushed, and then drop upon a grating with bars $\frac{7}{8}$ inch (23^{mm}) apart. That which is too coarse to pass through is returned to the crusher, whilst the fine goes to a set of separating and sizing trommels, for the purpose of being classified according to size.

The height at which the stone-breaker is erected above the two sizing trommels, which are on the general level of the works, renders these operations very easy.

The separating trommel has an inner screen of sheet-iron with holes of $\frac{9}{16}$ inch (14^{mm}) in diameter, and an outer screen with holes of $\frac{1}{6}$ inch (4^{mm}). The coarse stuff rejected by the inner screen is returned to the same crusher. The intermediate sizes go to one trommel, and the fine (below $\frac{1}{6}$ inch) to another.

The diameters of the holes of these two trommels are as follows:

1st trommel $\frac{7}{32}$ inch ($5.^{mm}2$); $\frac{9}{32}$ inch ($7.^{mm}2$); $\frac{13}{32}$ inch (10^{mm}).
2nd trommel $\frac{1}{20}$ inch ($1.^{mm}2$); $\frac{1}{12}$ inch (2^{mm}); $\frac{1}{9}$ inch ($2.^{mm}7$).

The result is that when the *rocks* have passed through the stone-breaker, crusher, and the trommels, we have obtained a sub-division into:

1. Lumps which go to the picking-tables.

2. Gravel sized by the trommels, varying from $\frac{1}{20}$ to $\frac{9}{16}$ inch ($1.^{mm}2$ to 14^{mm}).

3. Sands finer than $\frac{1}{20}$ inch ($1.^{mm}2$) obtained from the finest screen.

The *smalls* furnish the same classes of stuff. They are first tipped on to a grating with bars 1¼ inch (32^{mm}) apart; the coarser parts go to the picking-tables, whilst that which passes through is sized by a system of trommels exactly like those we have just described, save that the inner screen of the separating trommel has holes of ⅞ inch (23^{mm}). The stuff rejected by this screen is raised by an elevator to the staging, and then passes to the large rolls by which it is crushed and mixed with the products of the *rocks*.

(726) The sizing is now complete. The pieces larger than 1¼ inch (32^{mm}) go to the picking and cobbing-tables, which will be described later on, whilst those between 1¼ and ⅞ inch (32^{mm} and 23^{mm}) are returned to the crusher; and we must now describe the treatment of the different sizes from ⅞ inch (23^{mm}) downwards.

The stuff between ⅞ inch and ½ inch (23 to 12^{mm}) is treated in an intermittent jigger, which separates it into waste and mixed ore. The latter is hand-picked, and divided into clean galena fit for smelting, waste which is thrown away, and *dradge* which is re-crushed by a pair of medium-sized rolls.

The gravel between ½ inch and ⅜ inch (12^{mm} and 10^{mm}) is treated in another intermittent jigger; this divides it into rich galena, waste, and *dradge*, which is sent to the medium-sized crusher.

Lastly, all the smaller sizes, down to $\frac{1}{20}$ inch ($1.^{mm}2$) exclusively, are treated separately in continuous jiggers, each with two sieves, and two discharge-pipes to each sieve. They furnish the following products: clean galena at one end, waste at the other, and intermediate products (*dradge*) between. The latter are re-crushed, the coarser sizes by the medium rolls, and the finer by a pair of small rolls.

The medium rolls, like the large ones already referred to, are followed by separating and sizing trommels, and the different sizes pass on to different jiggers.

The small crusher has only one sizing trommel, with holes of $\frac{1}{20}$ inch and $\frac{1}{12}$ inch ($1.^{mm}2$ and 2^{mm}); the insufficiently crushed particles (*raff*) which will not pass through are turned into the elevator of the medium rolls and re-crushed.

While all these operations are going on, the picking and cobbing are being proceeded with, and furnish the following products:

1. Clean galena, fit for smelting.
2. Clean blende.
3. Mixed stuff containing galena and blende. If the works are arranged for the lead lode, the stuff rich in blende is put aside to be treated later on, and *vice versâ*.
4. Lastly, waste.

The mixed ore (*dradge*) is re-crushed by the large rolls, and so enters into the general circulation of the works.

(727) We must now see, lastly, what becomes of the sand of $\frac{1}{20}$ inch ($1.^{mm}2$) and under.

It has been brought into a proper state of suspension by the water which passes with it through the trommels, and it flows from all of them to a centrifugal pump, which raises and discharges it into an ascending current classifier with six compartments, each of which feeds a Hartz jigger.

The jiggers separate the stuff into clean galena fit for smelting, waste, which is thrown away, and three mixed products. The two first of these are always treated over again; but the third is re-jigged only occasionally, when a trial with a check jigger shows that it is worth while doing so.

The overflow of the first classifier is conveyed by a long pipe to a second similar one with eight compartments. Each pair of compartments feeds one of four rotating frames. These yield a certain quantity of clean galena and mixed products, which are returned to the centrifugal pump, and so re-enter into circulation.

Lastly, the water running off from the various machines in the works is conducted into settling-pits, of which there are two sets.

The first receives the water charged with the waste and refuse from the jiggers; the second, the rich slimes from all the machines, which are sent back to the centrifugal pump. Each set of pits is composed of two completely distinct series, so that one may be filled while the other is being emptied.

(728) Such then is the general series of operations carried out at the Castor dressing-floors.

We naturally remark that the machines employed successively for treating ores which are rich either in galena or blende might be simplified a little, if they were intended for operating upon a single ore which did not vary in quality; and, more particularly in the case of most of the jiggers, it would be sufficient to make two or three classes only, instead of going as far as four, which is necessary when blende is being treated.

In fact, though a little blende remaining in the galena may be neglected, as it is of too little value to pay the cost of extraction, it is essential to extract even small quantities of galena from the blende, because of its relatively higher price. Furthermore, the iron pyrites, which has a specific gravity nearly approaching that of blende, complicates the operations, and renders frequent successive treatments necessary. And if it is possible to obtain clean galena fit for smelting from the first compartment of the jiggers, and clean blende from the fourth, it is evidently necessary to be satisfied with mixtures requiring re-treatment in the case of the intermediate products.

Lastly, the copper pyrites and the carbonate of lead introduce another element of difficulty into the dressing. The remedy consists in separating the copper pyrites as much as possible by picking and cobbing, and neglecting any small quantities which still remain; whilst the carbonate of lead is allowed to collect with the galena, as the densities of the two minerals are nearly the same.

The plant of the works consists of the following machines:

1 stone-breaker.

3 pairs of rolls—large, medium, and small.

4 washing and separating trommels.

9 sizing trommels, one of them being small.

3 intermittent jiggers.

8 continuous jiggers, with 2 sieves and 4 discharge pipes.

7 Hartz jiggers, with 4 sieves each.

4 rotating frames.

1 centrifugal pump.

With this machinery it is possible to treat annually more than 22,000 tons of stuff, which yield about

340 tons of blende,
3500 tons of galena,
15 tons of copper pyrites.

According as the blende is in the state of lumps, gravel, or sand and slimes, it yields respectively 53, 46, or 44 per cent. of zinc. The galena yields on an average 63 per cent. of lead. This is a somewhat low percentage, and is due to the presence of spathose iron, which cannot be entirely got rid of without difficulty; and the galena could not be dressed cleaner without considerable loss, which it is important to avoid on account of the richness of the ore in silver.

We will add, in conclusion, that the consumption of water is 880 gallons (4 cubic metres) per minute, and the number of workmen employed is about eighty. They are distributed among the different departments as follows:

Overseers	3
Crushing and picking	16
Cleaning and sizing by trommels	43
Jigging and framing	17
Engine	1
Total	80

(729) We now come to the description of the opposite type of dressing-floors; viz., tin dressing-floors in England. We shall pass over it somewhat more rapidly, as there will be much less occasion to use it in France.

We have seen that the English machines are generally different from those of the Continent, and consist principally of stamps for crushing the ore, round buddles and keeves for concentrating the sands, and depositing-pits and frames for dressing the slimes.

The dressing operations are essentially intermittent, and therefore the relative position of the machines with regard to one another is far from being so important as in the preceding case, on account of their not being so much connected by belts or gearing.

This may be seen by Figure 523, which is a sketch plan of the dressing-floors at East Pool Mine.

These works possess sixty-four heads of stamps, which are all at work simultaneously, and are made to crush the ore very fine, on account of the cassiterite being minutely disseminated through the veinstuff. The stamped ore flows into long troughs (*strips*) in which the particles are deposited by order of equivalence. The deposit is divided into three parts; viz.:

1. *Head*, or rich upper part.
2. *Craze*, intermediate or middle part.
3. *Tail*, or poor part at the lower end.

Lastly, the water, charged with fine muddy particles, runs into the slime pits, where it forms a deposit.

Each of the three classes of sand deposited in the strips is first of all concentrated in round buddles, and then finished off in the keeves. The general principle of the process of dressing is not to send any stuff to the keeve until it has been well concentrated, by being buddled several times. The *bottom* of the keeve is then finished for a time, and is ready for calcination, whilst the *skimpings*, or top layers of the keeve, are returned to a round buddle, which is treating stuff of a somewhat similar degree of concentration.

The result is that the finished concentrate (called *whits*) is obtained solely from the bottoms of the keeves, whilst the poor waste is got rid of solely from the tails of the round buddles.

The treatment of the slimes is somewhat different, although it is carried out on the same principle, by means of frames and round buddles.

The first of the following tables, together with the plan of the works in figure 523, explains the complete series of operations from the stamping to the first calcination. This latter process is introduced into the dressing for the purpose of oxidising certain foreign minerals which injure the ore and would interfere with the smelting.

These minerals are mispickel, pyrites, &c. The roasting, or *burning* as it is usually called, removes almost all the sulphur and arsenic, and converts them into oxides or sulphates, which

are easily got rid of in the subsequent washings, on account of their lower specific gravities. Another injurious mineral—wolfram—still remains behind, and no means have been yet found of separating it in a practical and economical manner, in spite of the great depreciation in value, which is caused by its presence.*

The calcined ore is treated again in round buddles and keeves, in the same manner as before. The heads of the buddles when sufficiently concentrated go to the keeves, and these yield *bottoms* which are burnt a second time, and *skimpings* which are returned to the round buddles.

The sole difference between the treatments after the first burning and after the second consists in the fact that the bottoms of the keeve in the first case are re-burnt, whilst in the second they are subjected to the process of *chimming,* which is performed in a keeve tilted upon one side, and resembles the tossing and packing, but is somewhat more delicate. The bottoms of this last operation are fit for smelting, and are sold under the name of *black tin.*†

Tables 2 and 3 show the complete series of these last operations.

* Dr. Oxland's process for the separation of tungsten, viz. calcination with carbonate of soda and extraction of the soluble tungstate of soda by water, has been used successfully at Cornish mines, and is still in use at one mine in the county.

† At East Pool there are now (1886) 160 heads of stamps, which crush about 940 tons weekly, and produce 29 to 30 tons of black tin. The second calcination has been given up; and the *whits,* after the first burning, are at once dressed for black tin. On the other hand, all the mine-stuff likely to contain much wolfram is carefully picked by hand; the stones mixed with tungsten ore are then crushed by rolls, and the product dressed by jigging. The concentrate is calcined to get rid of sulphur and arsenic, and the burnt ore dressed by buddles and keeves until clean wolfram is obtained fit for sale. Jiggers are occasionally employed in Cornwall for concentrating tin ore, and their use could probably be extended with advantage.—*Translators.*

DRESSING AT EAST POOL MINE.

I. Table showing the Series of Operations from the Stamping to the First Calcination.

Stamps. The stamped stuff runs into strips.

- **Heads (A)** to buddle 2.
  - **Heads (E)** to buddle 3.
    - **Heads (K)** to the keeve.
      - **Bottom** (*whits*) ready for the calcination.
      - **Skimpings** to buddle 9.
        - **Heads (L)** to buddle 10.
          - **Heads (K)** to the keeves. (See above.)
          - **Craze** to the same.
          - **Tails** thrown away.
        - **Craze** to the same.
        - **Tails** thrown away.
    - **Craze (A)** to buddle 2. (See above.)
    - **Tails** to buddle 4.
      - **Heads (E)** to buddle 3. (See above.)
      - **Craze (E)** to buddle 3. (See above.)
      - **Tails** to the long strips. (See above.)
  - **Craze** re-treated in the same buddle.
  - **Tails (F)** to the long strips.
    - The deposit in the first of these strips is returned to the stamps.
- **Craze (B)** to buddle 1.
  - **Heads (A)** to buddle 2. (See above.)
  - **Craze** to the same buddle.
  - **Tails (F)** to the long strips. (See above.)
- **Tails (C)** to buddle 7.
  - **Heads (G)** to buddle 8.
    - **Heads (E)** to buddle 3. (See above.)
    - **Craze** to the same buddle.
    - **Tails** thrown away.
  - **Craze** to the same buddle.
  - **Tails** thrown away.
- **Overflow (D)** to slime-pits α.
  - **Slimes deposited (H)** to the frames.
    - **Deposit** to buddle 7 (C). (See above.)
    - **Overflow** to pit β (I). (See above.)
  - **Overflow (I)** to slime-pit β. [It gives a deposit (M), which goes to the buddles 13, 14, R_1, R_2, R_3, and slimy water, which flows away.]
    - **Heads (N)** to buddles 15 and 16.
      - **Heads** (*whits*) ready for burning.
      - **Craze** to the same buddle.
      - **Tails** thrown away.
    - **Tails** thrown away.

II. Table showing the Series of Operations from the First Calcination to the Second.

First Calcination. The calcined *whits* go to buddle 22.

- **Heads (B)** to the keeve.
  - **Bottom** to the second calcination.
  - **Skimpings (D)** to buddle 21.
    - **Heads (E)** to buddle 23.
      - **Heads (G)** to the keeve.
        - **Bottom** to the second calcination.
        - **Skimpings (E)** to buddle 23. (See above.)
      - **Craze** to the same buddle.
      - **Tails (H)** to buddles 26 and 27.
        - **Heads (B)** to the keeve. (See above.)
        - **Craze** to the same buddles.
        - **Tails (I)** to the pulverizer. [The pulverized stuff goes to the two buddles R_1 and R_2.]
          - **Heads (K)** to the keeve.
            - **Bottom** to the second calcination.
            - **Skimpings (L)** to buddles 15 and 16. (See above.)
          - **Tails (L)** to buddles 15 and 16.
            - **Heads (K)** to the keeve. (See above.)
            - **Craze** to the same buddles.
            - **Tails** thrown away.
          - **Overflow** to a slime-pit, which gives slimes that go to buddles 15 and 16 (L). (See above.)
    - **Craze** to the same.
    - **Tails (F)** to buddle 25.
      - **Heads (H)** to buddles 26 and 27. (See above.)
      - **Tails (I)** to the pulverizer. (See above.)
- **Craze** to the same buddle.
- **Tails (C)** to buddle 24.
  - **Heads (A)** to buddle 22. (See above.)
  - **Craze** to the same buddle.
  - **Tails (I)** to the pulverizer. (See above.)

III. Table showing the Series of Operations from the Second Calcination to the End.

After the second calcination the stuff passes to buddle 18.	HEADS (A) to the keeve.	BOTTOM is buddled over several times.	FINAL HEAD (D) is *chimmed* (in the inclined keeve).	BOTTOM finished.
				SKIMPINGS to the buddle.
		SKIMPINGS to buddle 20.		
	CRAZE (B) to the keeve.	Treated in the same way as (A).		
	TAILS (C) to the keeve.	Treated in the same way as (A).		

All the intermediate products are buddled over again until the foreman or captain ascertains by washing a sample on a shovel (*vanning*) that the stuff is fit for being *chimmed*.

(730) The preceding remarks furnish the data necessary for the technical study of the question of dressing the various ores most often met with in practice. In order to render them complete, it would be necessary to give some information concerning the cost of each separate dressing process, and the total cost of treatment.

Unfortunately this is not possible. The cost varies so much with the richness of the raw ore and the amount of concentration required, with the more or less complex nature of the ore, with the kind of machinery used, and the more or less convenient way in which it is arranged, &c. &c., that it is impossible to lay down any general figures. All that could be done would be to quote certain special examples. But in addition to the fact that this information is not readily made public by mining companies, it may be said *a priori* that we should probably never have to deal with two exactly identical cases. The information would consequently lose much of its interest.

The result is, that an engineer designing dressing-floors will have great difficulty in estimating the working cost beforehand. He will be able to plan the arrangement of the works, and estimate the cost of the machinery; but there will always be uncertainty, partly with reference to the labour required for shifting the stuff about, and principally with reference to the loss in dressing. This subject is one which requires continual attention, and, if necessary, the treatment must be modified, so as to reduce the loss as much as possible; for instance, by making alterations in the crushing or sizing processes, and in the amount of stuff to be treated over again, by insisting more or less upon the cobbing and picking, and by carefully watching the refuse which is thrown away.

However, we will here give the figures quoted by M. Huet as the *average* cost per ton of dressing the ores which are most frequently met with in France:

	Per statute ton.			Per metric ton.	
	s.	*d.*		Frs.	Cs.
Iron Ore	0	2	...	0	20
Manganese Ore	7	10	...	9	65
Coarse-grained Galena	5	10	...	7	20
Fine-grained Galena	7	10	...	9	65

	s.	d.		Frs.	Cs.
Coarse-grained Galena and Blende .	9	10	...	12	10
Fine-grained Galena and Blende .	11	10	...	14	55
Copper Pyrites or Grey Copper Ore with Iron Pyrites . . .	9	9½	...	12	05
Copper Pyrites or Grey Copper Ore with Galena . . .	13	10	...	17	00
Copper Ore, Galena, and Blende .	20	4	...	25	00

§ 2. Gold Washing.

(731) In addition to the description we have already given of the methods of dressing the more common ores, we propose to say a few words about the treatment of ores containing native gold, albeit the methods here referred to have not yet been applied in Europe. For not only is it possible that occasion for their use may arise,* but it is also interesting to point out, at all events briefly, how certain special difficulties have been overcome in treating gold ore, which are due both to the very small yield of the stuff and to the extreme minuteness of the particles or scales of metal contained in it.

We need not here describe the remarkable methods employed for working the auriferous deposits. As is well known, gold occurs in quartz veins and in alluvial deposits (*placers*): the veins and some placers are worked by the ordinary mining processes, whilst other beds of auriferous gravel, especially in California, are excavated on an enormous scale by jets of water under great pressure (*hydraulic mining*), as pointed out in paragraph 132; lastly the sand and gravel of existing river-beds are worked by the ordinary methods after the course of the river has been diverted, supposing this to be practicable, or if not, the sand is drawn up from the bottom, or even from below the bottom, by means of the Bazin pipette (fig. 524).

This pipette is a kind of hollow, ovoid vessel of sheet copper fixed at the end of a long pole. It can be forced into wet running sand, and its lower end can be closed or opened at pleasure by means of a wooden ball attached to a cord.

* Gold alluvia are now being worked by the hydraulic method in the North of Spain.—*Translators.*

The apparatus, with its lower end closed, is forced down until it reaches the stratum which has been proved, or is supposed, to contain gold. The ball is now removed, and the hydrostatic pressure forces a mixture of sand and water into the interior of the vessel. The ball is then drawn on to the opening, and the apparatus raised to the surface.

This is a most useful prospecting apparatus, and it may even be used for working a river bed if the ground is rich enough, and if the water cannot be diverted.

(732) Putting aside for the moment the consideration of the impalpable powder produced in the operation of crushing gold-bearing quartz, we shall suppose that the matter we are treating consists of more or less coarse-grained sand containing gold in the form of nuggets, grains, and especially scales, and we shall proceed to examine the various processes employed in separating the metal.

The oldest, most primitive, and most costly, but at the same time most perfect method, is that of the *pan* or *batea*. It is hardly employed at all now-a-days except for experimental purposes, or for final concentration. The pan is a round, hollow dish, 16 to 20 inches (40 to 45 centimetres) in diameter, and 4 or 5 inches (12 centimetres) deep, made of tin-plate or sheet-iron. The batea is a round, conical dish, made of wood, 18 to 24 inches in diameter, and 2 to 2½ inches deep in the centre. The batea or the pan is filled to the extent of two-thirds its capacity with the auriferous earth, and then dipped into water, and the contents thoroughly wetted. A series of oscillatory movements are given to it by hand, while it is inclined successively in all directions, or it is made to revolve round its vertical axis. These movements cause the clayey sand to be gradually washed out, and at length the mixture remaining at the bottom consists only of the heaviest stuff, such as grains of quartz, magnetic iron, &c., and scales of gold.

The quartz grains are taken out by hand, those of magnetic iron by means of a magnet, and the gold is left at the bottom.

(733) Bazin's centrifugal hydraulic washer (fig. 525), which is a comparatively recent invention, is a batea worked mechanically, and therefore in a much more economical manner than the one just described.

This washer consists of a cylindrical sheet-iron tub filled with water, having an iron rod in the centre supporting a small copper washing-basin.

The basin is turned round by a handle, and this movement creates centrifugal force enough to drive out its contents with greater or less rapidity according to the curvature of its sides. A few turns of the machine cause a gyratory motion sufficient to carry the sand out of the basin, after which it falls to the bottom of the tub; meanwhile the scales of gold remain on the inclined sides of the basin, and can be collected at the bottom along with the coarser particles.

There are several ingenious arrangements for rendering the work easy. In the first place, the basin is provided with a round copper dish, forming a false bottom, which can be lifted up by itself in order to collect the heavy particles which have settled upon it; secondly, an india-rubber pipe, which can be turned into a siphon by lowering its outer end, serves to draw off the sand from the bottom of the tub by the pressure of the water contained in it; thirdly, there are brackets for conveniently holding such basins of various shapes as may be required in the process of washing, &c.

In a word, this apparatus is easily taken from place to place, an important matter in gold-washing, and it has the great advantage over the pan and the batea, that it can be worked by inexperienced men, and does not require skilful handling as they do. With this machine two men can wash five or six tons of stuff in a day, the result being a highly-enriched product, which can be easily cleaned in the batea.

(734) Long before the invention of the hydraulic washer, the wish to substitute a more economical apparatus for the long, difficult, and intermittent operations of the pan had led to the invention, first, of the *cradle* or *rocker*, and then of the *long tom*.

The former (fig. 526) consists of a rectangular wooden box about 3 feet 3 inches (1 metre) long by 20 inches (0·50 metre) wide, open at one end, closed at the other, and resting on two rockers, like those of a child's cradle, which enable it to be moved to and fro about an axis parallel to its length. A removable smaller box or hopper is placed at the closed end, with its bottom made of perforated sheet-iron, which stops the large stones. Underneath it there is an inclined canvas apron, which turns the stream towards the closed end. Lastly, two transverse bars (*riffles*), about ¾ inch (2 centimetres) thick, are nailed to the bottom—which slopes down slightly towards the open end—one being fixed in the middle, the other near the end.

The *pay dirt* is thrown into the hopper, and water is poured on whilst the cradle is rocked. The fine stuff goes down with the stream, the gold and heavy sands are caught behind the riffles, whilst the lighter particles are washed away.

The rich sand obtained in this way is finally washed in a pan or batea.

If the gold occurs in very fine particles, the cradle will not catch them all, and much is lost. This is particularly vexatious, on account of the great value of the gold.

In order to remedy this defect, the canvas has been replaced by a blanket, whose filaments retain between them a large proportion of the fine gold, which virtually convert it into a *golden fleece*. But this is only a palliative, and in a case of this kind recourse is generally had to the *long tom*, which has the further advantage of treating stuff twice as fast as the cradle.

It is a wooden trough, about 11 feet 6 inches ($3.^{m}50$) long by 1 foot 8 inches ($0.^{m}50$) wide at the head; it gradually widens towards the other end, which is closed by a plate of perforated sheet-iron. This riddle, like that of the cradle, stops the large stones. Below it is fixed an inclined wooden box, with transverse bars, or riffles. Sometimes mercury is placed behind the riffles to catch the gold by amalgamation.*

* For figures and description of long tom and riffle-box see "The Mining and Metallurgy of Gold and Silver," by J. Arthur Phillips, p. 138; and "The Gold Fields of Victoria," by R. Brough Smyth, p. 615. The long tom figured by the latter is 24 feet in length.—*Translators.*

(735) This machine contains the original idea of the *sluice-boxes* employed on a large scale in the great hydraulic workings of California, and for that reason we will dwell upon them somewhat more at length. Sluice-boxes are wooden troughs 3 feet 4 inches (1 metre) to 6 feet ($1^{\cdot m}80$) wide, and about 3 feet 4 inches (1 metre) deep. Each box is generally 12 feet long, and the boxes are put together one after the other, so as to form long lengths of 1000 or even 2000 yards. The inclination or *grade* varies, according to the supply of water, from 1 in 50 to 1 in 17.*

The bottom (fig. 527) is formed of poles, blocks of wood, or stone, leaving interstices between them; whilst in order to protect the sides from the wear of the gravel, lining-boards, which can easily be replaced, are sometimes added.

The bottom, whether of wood or stone, must be fixed very firmly, so that no part can be lifted up and carried away by the stream, which, when once a gap is formed, will soon destroy a great length of the sluice. The interstices are then filled up with sand, clay, or small stones, and mercury is poured on† with an iron watering-pot at the rate of about 33 to 35 lbs. per 100 yards (15 to 16 kilos. per 100 metres), a little more at the head, and a little less at the tail end. More mercury has to be added, from time to time, to take the place of that which is gradually carried downwards by gravity, owing to the capillary action of the pavement being incapable of retaining it.

The boxes being thus prepared, the stream of water carrying the pay dirt with it is turned on. The scales or grains of gold sink down, meet the mercury, and amalgamate with it, whilst the pebbles and sand roll along and are washed away.

(736) But the rapidity of the stream, which tends to wash away everything with great force, causes considerable losses, which are prevented to some extent in two different ways.

The current in any case must be strong enough to carry away

* J. Arthur Phillips (*Op. cit.* p. 140) says, "The grade is commonly from ten to eighteen inches on each box of twelve feet in length." This would be 1 in 14 to 1 in 8. A six-inch grade, or 1 in 24, is common.—*Translators.*

† J. Arthur Phillips, *Op. cit.* p. 142. The mercury is not poured in until about one hour and a half to two hours after the commencement of sluicing.—*Translators.*

even the largest fragments; but if the large stones are removed, the grade can be lessened. This removal of the large stones is effected by the so-called *grizzly*—a grating made of bars of iron, over which the stones roll and are discharged. The second device for saving gold consists in putting in *under-currents* here and there, which separate the fine gravel and sand, and admit of their being treated separately.

The under-current is a shallow box 10 feet (3 m.) or more wide by 30 to 60 feet (10 to 20 metres) long, upon the bottom of which are fastened close together a number of wooden bars or iron rails (*riffles*) charged with mercury. The under-current is fixed at a place where the bottom of the sluice box is made of bars of steel or chilled cast-iron $\frac{3}{8}$ inch to $\frac{3}{4}$ inch (1 to 2 centimetres) apart, and it receives a part of the stream with the finer particles. The stream is distributed evenly over the under-current by means of a few wooden *dividers* at the head, and when it reaches the tail it falls into the general current. As the inclination of the under-current is less than the general grade of the sluice boxes, nearly all the gold passing over it can be caught.

All that remains to be done is to clean up from time to time, once or twice a month, and collect the amalgam in the sluice boxes and on the under-currents. A strong stream is first turned in to wash down the stones and pebbles, and then nothing but a little clean water is allowed to run down, beginning at the top. The paving blocks are removed one after the other and washed, and the amalgam is collected by putting at intervals of every 100 feet (30 metres) a tight stop at the bottom of the sluice box. The amalgam is washed in a pan or batea, and squeezed through canvas or chamois-leather; the product is distilled.

The quantity of water required is about 10 cubic feet of water per cubic foot of gravel.

(737) Such then is the very simple method employed for treating the immense beds of gold-bearing alluvium in California.*

* For full details and figures consult "A Practical Treatise on Hydraulic Mining in California." By Aug. J. Bowie, jun., New York, 1885.—*Translators.*

It is rapid and economical; but we may safely assume that it causes a great loss of gold, although the exact amount is not known. It is easy to imagine that some of the particles of gold slide over the surface of the mercury in the boxes, when it has become a little dirty and covered with oxide, and are lost by being carried away with the sand and gravel in the stream.

Bazin's *mercurial washer* (fig. 528), which however has not yet been employed on a large scale, seems likely to overcome this difficulty. It resembles the hydraulic washer in principle, as the waste is discharged by centrifugal force due to the rotation of a spherical basin, but it differs from it by having a cylindrical cup at the bottom full of mercury. The stuff is brought in under the mercury by means of a vertical pipe full of water, provided with a funnel-shaped top for convenience of charging.

When at rest the column of water must be high enough to balance the small mercurial column in the basin; and it is easy to conceive that when water and sand are turned in at the top the equilibrium is destroyed, they escape at the bottom, rise up through the mercury, and are at once discharged by the gyratory movement of the basin. The particles of gold, however, kept back partly by their specific gravity and partly by their affinity for the mercury, stay at the bottom and become amalgamated.

If necessary an internal screw may be employed to retard the passage of the sand and mix it more intimately with the mercury.

It is evident that this machine is suitable only for somewhat fine sand, and that it could not treat coarse alluvial gravels unless they had been previously subjected to a proper sizing process; but it appears adapted for fine stuff, and especially for stamped vein quartz, when very fine crushing is requisite.

Stuff of this kind, which has hitherto been treated in a very imperfect manner by means of barrels or other receptacles, in which it is mixed or churned up with a certain quantity of mercury by suitably-arranged agitators, could probably be passed with advantage through a mercurial washer. The stuff has in a manner to flow through the mercury, so that no particle can

escape contact with it. We have not sufficient data for pronouncing a final opinion upon this machine. It appears, however, from assays made while experiments were in progress, that the loss of gold would not exceed 10 per cent., and might even be very much less.

(738) The cost of treating a ton of stuff with the machines we have been describing varies according to the daily wages which have to be paid, and these vary greatly on account of the special circumstances under which the deposits are found.

From average data it appears that the amounts that can be treated by each kind of apparatus per man and per day are:

	Cubic yards.	Cubic metres.
Pan . . .	0·26	(0·20)
Cradle . . .	1·00	(0·80)
Long Tom . . .	2 to 2·6	(1½ to 2)
Hydraulic Washer . .	1·3 to 2	(1 to 1·5)
Mercurial Washer . .	1·3 to 2	(1 to 1·5)

The amount that can be worked by a sluice box is very variable, according to the grade of the boxes and the rapidity of the stream; but in all cases it is very large, and consequently the cost of treating a cubic yard, which varies from 3s. to 6s. with the preceding machines (5 to 10 francs per cubic metre), wages being 8s. to 12s. a day, is reduced to 1d., 1½d., or 2d.* (15, 20, or 25 centimes per cubic metre), according to circumstances.

It is true, however, that sluicing can only be employed under certain special conditions, that it requires a considerable outlay in preparatory works, and lastly, that to form a proper idea of its results it would be necessary to know the amount of loss it occasions. This loss has never been measured exactly, but it may fairly be supposed to be large.†

* 2½d. (5 U.S. cents) is given as the average cost per cubic yard of gravel moved. —*Min. and Eng. Jour.*, New York, vol. xli., 1886, p. 246.

† Where the discharge of boulders, gravel, and trailing would injure agricultural land or navigable rivers, the working of hydraulic mines has been stopped by law in California. *Min. and Scien. Press*, San Francisco, vol. lx., 1885, p. 57; and *Min. and Eng. Jour.*, New York, vol. xl., 1885, p. 184.—*Translators.*

§ 3. Coal Washing.

(739) Although the observations made in the previous chapters refer chiefly to metallic ores, to which the term dressing is more particularly applied, they are nevertheless not without interest to those who are studying the various processes to which coal is subjected before being delivered to the consumer.

This treatment is of comparatively recent date, for the time is not long gone by when small coal of every kind was thrown away, or burned in heaps, as a substance of no value whatever; it is necessitated by the presence of the impurities generally found associated with coal, and whose removal is amply justified by the remarkable advantages thereby obtained from a metallurgical point of view.

These impurities consist principally of shale, iron pyrites, clay ironstone, sulphate and carbonate of lime, &c., all more or less intimately mixed together, more or less disseminated along the planes of cleat or bedding, and generally separable from the coal if the mechanical subdivision is carried far enough.

Independently of the saving in cost of carriage of which we have spoken in paragraph 612, the removal of the impurities produces a noteworthy economy in the cost of keeping fire-bars in repair, by the withdrawal of the iron pyrites; it also ensures a greater heating effect, which is of the first importance in certain cases, and notably so in the case of railways and steam-boats; and, lastly, it improves the quality of coke, which is of considerable advantage in increasing the output of blast furnaces, making them run regularly, facilitating the work, and producing a better quality of metal.

(740) The operations which are undertaken with this object, although based on the same principles as those previously described, yet differ from them to a considerable extent in their mode of application, both as regards the object to be attained and the means employed.

In treating metallic ores the principal object aimed at is to obtain by a series of successive operations a product small in bulk perhaps, but giving as large a yield as possible, since the selling price is fixed after an assay. Furthermore, a diminution of

the yield, amounting to only a few units per cent., as we have seen in paragraph 617, increases in importance as the ore becomes poorer; and, lastly, the limits to mechanical preparation are fixed by the cost and by the losses, which increase continually as the operations are prolonged, and would soon become equal to, or greater than, the profit resulting from the concentration. In sales of coal, on the other hand, a maximum yield of ash is fixed in advance by the purchaser,* who does not as a rule give a higher price if the coal is better than his standard; the object aimed at in purifying coal is therefore to arrive at this maximum yield as exactly as possible by removing shale, pyrites, &c., and every step the mine-owner takes in making his produce of greater value than is stated in the contract raises the cost of the operations, increases the losses, and withdraws a corresponding part of his profit.

It is necessary to remark further that although a careful classification according to size has been hitherto neglected by the majority of mine-owners, it is generally considered of great advantage, because it almost always enables the coal to be utilized more easily. The consequence is that sizing is frequently one of the objects aimed at in dressing coal, whereas in the case of dressing metallic ores it is simply a necessary intermediate operation in the process of concentration.

Finally, the conditions as regards quantity and value of the products are, as a rule, entirely opposite. In the case of metallic ores, we have to operate upon small quantities of valuable substances, which, as we have seen above, admit of our having recourse to delicate contrivances and frequent repetitions of the same process, notwithstanding the amount of capital required and the high cost of labour entailed by it. In the case of coal, on the contrary, we are dealing with enormous masses of a substance of little value, the profit upon which is reduced to a minimum by competition. We are consequently forced to employ special machines, as simple as possible, acting automatically, as far as practicable, and capable of treating considerable quantities. We must generally abandon all idea of treating coal by frequent repetitions of the same process, or, at all events, do so sparingly,

* Rarely if ever done in this country, though undoubtedly advantageous. —*Translators.*

so as not to burden it with too heavy costs. And finally, in planning the whole arrangement and the means of transport, we must have recourse to the best mechanical contrivances, so as to carry out the operations both with simplicity and economy.

(741) Notwithstanding the difference which from the preceding observations appears to exist between the two methods of procedure, it is nevertheless remarkable that the same character and the same general features are to be found in both. These are: preliminary picking, followed by crushing, sizing, and washing; but the various operations do not in this case preserve the same relative value. In treating coal, the picking is less careful, the crushing is much less complete, is sometimes entirely omitted, and is not usually employed at all, except for special purposes, namely, the production of an intimate mixture of the whole mass, when coke or patent fuel is to be made from it. The classification according to size has also remained until now in a rudimental state, compared with the similar process for treating metallic ores. Lastly, all these preliminary operations possess a much smaller relative importance, in comparison with the final and principal operation of washing.

On the other hand, the nature of the substance to be treated, which at first sight seems to be so simple as to render the method of treatment an easy matter, is, on the contrary, eminently variable and complicated, and hardly admits of the establishment of general rules, or allows us to pronounce an opinion as to the respective merits of the various machines in use. The more or less friable nature of the coal, compared with that of the bands of shale contained in it, the greater or less solidity of the roof and floor, the nature of the pyrites and its position in the seam, whether more or less intimately mixed with it, or contained in flat pieces associated with shales, &c., are all circumstances that tend to produce a variation in the yield of ash of the large and small coal respectively, and consequently altogether different rules must be followed in treating them. It is hardly possible to enunciate these rules even in a general manner, and long practice, or the glance of an experienced

eye, cannot always pronounce positively which are the best methods in any particular case.

(742) The first operation to which coal is subjected is picking, which often accompanies the process of classifying according to size. We shall not tarry long in describing this part of the preparation, which resembles, to a great extent, the analogous operation to which metallic ores are subjected, but is carried out on a much larger scale, and in a less perfect manner.

The large coal is usually picked out by hand underground, and sent to the surface separately, in a fit state for loading into waggons and being sent to the market without further preparation. We have only to concern ourselves about the mixed qualities, or *through-and-through.*

This mixed quality is passed on to inclined screens, with a width of 1½ to 2 inches* (4 to 5 centimetres) between the bars. The part that does not fall through is picked by hand by boys or women on fixed or even revolving tables, similar to those described in paragraph 632. This arrangement, although very convenient and largely applied in Germany, is little used in France.†

The picked coal goes directly to the market, and often without a further classification according to size, at least in France; the shale is thrown away.

The coal that passes through the screen constitutes the *small.* It is a mixture in various proportions of grains, peas, nuts, &c., with the dust or dead small; that is to say, it consists of particles of every size—from the largest that can pass between the bars of the screen, or through the holes of the sifting apparatus, to the finest dust.

When the coal is clean enough, this small can be sent directly to the market, either before or after classifying it according to size. But if otherwise, which is the more general case, the gradually-increasing exigencies of commerce in regard to the proportion of ash tend more and more to force the mine-owner to submit it to a washing operation, and consequently to a classification by size, which is more or less careful or summary according to circumstances.

* 1⅛ inch is the distance commonly fixed in the steam-coal leases of South Wales.

† It is also seldom adopted in Great Britain.—*Translators.*

(743) The rules for sizing have been explained in paragraph 649, and we shall not repeat them here. But it must be remembered that in the case of the separation of coal and shale, in virtue of their densities, there is no necessity for making too close a classification. At the same time care must be taken not to make this fact an excuse for slurring over the sizing, as there is a tendency to do in practice, under the pretext that too much dust will be produced by the successive siftings, owing to the excessively friable nature of the substance treated.

It is necessary, however, to pay attention to the manner in which the coal breaks up, in order to decide upon the proper method of treatment for each particular case.

For ordinary kinds of coal it is well to make at least four or five different sorts, which will be treated separately in the washing machines respectively suitable for each of them. But sometimes fewer varieties are made, and sometimes none at all, when the sizing is omitted altogether.

The kinds of apparatus employed may either be cast-iron plates with holes in them, or, better still, fixed or shaking screens. But in this case, as well as in the one we formerly considered, the revolving screens constitute the most economical and the best solution of the question, as well as the most satisfactory one in regard to the results, although the objection is often made that they break the coal too much.

The thick and annoying clouds of dust which are generally raised in the picking and screening sheds can more easily be avoided with these trommels, as they can be half enclosed, or, better still, wholly enclosed in wooden boxes, as has been done at Bességes.

As the revolving screens have not in this case to serve as cleaning machines, a large quantity of stuff can be easily passed through them, even when they are of small dimensions. They may be made 5 feet to $6\frac{1}{2}$ feet ($1.^{m}50$ to 2 metres) long, and 4 feet to 5 feet ($1.^{m}2$ to $1.^{m}5$) in diameter, and they may rotate at the rate of 12 to 15 revolutions per minute. They may consist of one or two screens, and may either be slightly inclined or horizontal; in the latter case they are provided with an internal

screw for forcing the coal to move towards the discharge end. Lastly, they are sometimes divided into two or more compartments, and the screens are either perforated plates, gratings made of bars, or wire gauze; but there is nothing new in this, nor different from what we have seen in considering the case of metallic ores.

(744) We may, however, in certain exceptional cases, have to deal with varieties of coal of a totally different nature, which will completely alter the conditions of treatment. This is the case in America, or at least in Pennsylvania, in regard to anthracite.

This coal, which is otherwise of excellent quality, but difficult to kindle, does not decrepitate, and consequently requires to be burned under special conditions.

In order that the process of combustion may go on favourably, it is necessary not only that the lumps be not too large, so as to avoid having too great a cold mass in comparison with the red-hot surface, but the fragments must also be nearly all about the same size, in order that the whole of them may come under the action of the flame, and that the interspaces be not filled up with smaller pieces.

This last condition evidently excludes the use of the dust, which is consequently almost quite useless, as it cannot be employed in the manufacture of coke.

The result of all this is that the size of the lumps may not be greater than about 5½ inches (14 centimetres), or smaller than about 1 inch (2½ millimetres); but the hard and compact nature of anthracite enables a very careful classification to be made between these two limits, and without too much loss, even when thirteen distinct sizes are separated. It is evident that this sizing, which is carried on with large quantities, requires the employment of machines thoroughly adapted to the work they have to perform, and mechanical arrangements of such a nature as to ensure the solidity and the convenience of the whole.

Figure 529, for which we are indebted to the kindness of Mr. Eckley Coxe, represents one part of the anthracite dressing-works or *coal breaker* at Drifton, in Pennsylvania, which will be described

more completely further on. The coal first passes over screens having cast-iron bars 5½ inches apart; the ends of the bars rest in notches in the cast-iron frame supporting them, in such a manner as to permit of their distance apart being varied as desired. The figure explains how the coal which has passed through the screen is crushed, and is then classified in two trommels, each with two screens, thus producing five different sizes.

It is necessary to bear in mind that this figure represents only a small part of the establishment, and that the process of sizing is continued both for the large, which passes over the screen, and for the small, which passes through the outer perforated plate of the second revolving-screen.

There is no example on the continent of Europe of such complete sizing machinery as this, because the nature of the coal does not require such a degree of exactness, and its friability renders such a long series of operations out of the question.

(**745**) This sizing evidently necessitates as an indispensable adjunct a preliminary crushing, and the conditions of this process depend either on the dimensions of the lumps that are sent out of the mine, or on the relative proportions of the different sizes, and the requirements of the market.

The machines employed for this purpose are rolls which differ but slightly from those which we have described for metallic ores. The only difference is that they are made with teeth which are well adapted for insuring regularity in the crushing, and it is possible to use them in this case, because the substances they are working upon are comparatively easily broken.

Figure 530 is an example of a crusher of this kind in which the following features will be particularly remarked:

1. The shape of the cast-steel teeth, and the manner in which they are held in the rolls, so that if one of them is broken it is only necessary to drive the stump into the inside of the roll by means of a punch, and at once replace it by another tooth of the same pattern.

2. The arrangement by which the rolls are prevented from being broken or their shafts from being bent if a piece of hard shale or

other foreign material gets between the teeth. This arrangement, which is here rendered necessary because the two rolls are connected by cog-wheels, consists in making each plummer-block of one of the axles rest against a *breaking* or *safety piece*, which will give way before the strain becomes dangerous to the other parts, and in making the outside of these plummer-blocks of cylindrical shape vertically; this enables the shaft to be slewed round without being bent in case of the breakage of one of the safety-pieces.

(**746**) This crushing, for the purpose of supplying the market with pieces of coal of given dimensions, is quite unknown in France; but, on the other hand, a similar operation is often carried on with the small coal of various dimensions, intended to be washed previously to being made into patent fuel or coke.

In the latter case, indeed, we must remark that the coal as it comes from the washing machines, however well washed it may be, is essentially heterogeneous, for it contains not only perfectly pure coal, but also fragments of partings or rib material, small pieces of shale, and lastly, more or less impure dust.

The process of coking has little or no effect upon the shales, whilst the coal, on the other hand, swells up and assumes a characteristic appearance which is altogether *sui generis*, and the result is that the impurities tend to show themselves in the coke, and to give it a bad appearance, which greatly depreciates its value.

It is for the purpose of obviating this defect, as well as for obtaining in certain cases a complete mixture of several different kinds of coals, which would otherwise produce a similarly ill-looking coke, that it has been found expedient to crush the coal intended for coking. The object is to obtain a uniform distribution of the impurities throughout the whole mass, to produce an intimate mixture in fact, and consequently to give the produce a perfectly homogeneous appearance.

The machines usually employed in France for this purpose are *ordinary rolls, conical mills,* and *Carr's disintegrators.*

We do not propose to further describe the ordinary crushing rolls, which present no kind of peculiar feature, save that they

are often fluted, or provided with transverse grooves; and we shall merely say a few words about the two other machines which we have had no opportunity of describing until now.

The conical mills consist of two upright toothed cones, one movable, and standing within the other, which is fixed. The fragments of coal are seized and crushed between them, and escape by the lower opening (fig. 531).

In order that the pieces of coal may be caught properly, and crushed between the two conical surfaces, it is necessary that the teeth of the moving cone be set at a certain angle with those of the fixed part, and in practice this is generally 5° or 6°, as is shown in figure *a*, which represents the development of part of the conical surface.

Suitable arrangements, similar to those we have seen in the third volume of the *Cours des Machines*, admit of the axis being properly centered, and of its being raised, if required, to the suitable height.

A mill of this kind, which must be made of the best cast-iron, will grind 10 or 15 tons an hour.

Lastly, Carr's disintegrator (fig. 532) consists essentially of two iron discs, each cast in one piece with its hollow axle, which revolve on a steel shaft in opposite directions at a high velocity.

Each disc carries two circles of steel bars, joined together at their free ends by a wrought-iron ring, to which they are screwed.

The coal, which passes into the machine from a hopper on one side, should not be larger than about ¾ of an inch (2 centimetres) in diameter. It is caught by the bars and subjected to a rapid succession of blows, which pulverize it finely, and it falls through an opening in the lower part of the apparatus, into receptacles placed there for the purpose.

The whole machine is enclosed in a sheet-iron case.

A disintegrator of this kind, 4 feet in diameter ($1.^{m}2$), and making 100, 200, and even 300 revolutions per minute, according to the hardness of the coal, will grind 15 tons per hour. It performs its work admirably, but requires considerably more power to drive it than ordinary rolls, and costs more both originally and for repairs.

(**747**) These preliminary operations being well understood, we must now suppose that we are dealing with coal which has been sufficiently crushed, and varies in size from ¾ in, 1 in, and even 1½ inch at the most (2, 3, and even 4 centimetres) to the finest dust; it is generally divided, by a process of screening, into four or five categories, each of which has to be washed separately, in order to extract the shale, pyrites, clayey matters, &c., which diminish the purity of the coal.

The problem to be solved, which we have just stated in a general manner, is therefore somewhat complex.

It is necessary to realize the fact that the process of sizing a friable and brittle substance requires to be performed somewhat quickly, and cannot give such exact results, as in the case of metallic ores. Furthermore, as a natural consequence, any category coming from a certain subdivision of the classifying machine is not of uniform size, but consists of fragments of every dimension, from the particular size of the category under consideration to that of impalpable powder. And lastly, many of the fragments with a splintery or conchoidal fracture are of such an irregular shape as to interfere with the classifying process, &c.

The difference, sometimes very considerable, which exists in a given class between the proportions of large, of small, and of dust, and also the variety of their composition, and consequently of their density, which passes through all the stages between that of pure coal and shale, introduce again other variables into the question, and their effects must be added to the preceding ones. Although the difficulties which arise from all these causes are partly compensated, not only by the fact that the classification need not be very exact, but also by the relatively high percentage of ash which is still permitted in the market, it is nevertheless true that coal washing presents a series of problems sufficiently difficult and complicated to have hitherto defied the enunciation of general rules, and to have divided the opinions of the most competent engineers.

(**748**) As we have already seen, this process of washing depends upon principles which are identical with those that regulate the mechanical preparation of metallic ores; that is to say, on the

conditions which accompany the fall of solid matter in deep or shallow water. These various conditions have been already discussed in paragraphs 649 to 675, and we need not return to them here. The work is performed by means of similar machines to those described, the most ancient of all being naturally the hand jigger, with discontinuous action and a moving sieve.

This machine, which has become quite obsolete at the present day, at least in its primitive form, has been gradually altered by a series of successive modifications, similar to those which the ore jigger has undergone. The jiggers came to be worked by machinery, and finally people adopted the continuous jigger with fixed sieve and lateral piston; and this is the sole type of jigger employed at the present day, although there are numerous varieties of it.

The standard type of these machines, known as the piston-jig, consists of a wooden box divided by a partition into two compartments of unequal size. The sieve is fastened in the larger compartment, and the coal to be washed lies upon it. The smaller compartment, on the other hand, which is about half the size of the first, and communicates with it across its whole width at the bottom, serves as a working-barrel for a floating piston. The piston receives its motion from cams fixed on a revolving shaft, which cause it to descend suddenly, thereby driving the water up through the meshes of the sieve and raising the charge. It returns to its former position of its own accord, being lifted by the returning water. In general, it makes 33 strokes a minute, each 3 or 4 inches (8 to 10 centimetres) long.

A whole host of machines have been constructed on the model of this primitive and, as it were, fundamental type.

Confining ourselves only to those which afford some guarantee for good results by being constructed in a manner adapted to the work they have to perform, we may point out the following points of similarity:

In the first place, they are large enough to treat considerable quantities of stuff, without causing too rapid or too great variations in the thicknesses of the beds of small coal and shale during the work, and consequently without producing any sensible alteration in the conditions of washing.

In the second place, suitable proportions between the dimensions of the piston and those of the sieve, proper arrangements for producing a regular and uniform action of the water upon the stuff, the regulation of the number and length of the strokes according to the size of the fragments to be treated, and the degree of purity required.

Lastly, arrangements for feeding regularly, and discharging the coal and shale automatically and continuously, as well as mechanical arrangements for making the operation rapid and easy, and thereby ensuring economy in manual labour.

(749) The first example we shall choose as constituting a very perfect type, but at the same time preserving all the characteristics of the jigger, properly so-called, is that of *Molières*, near Bességes.

It is represented in fig. 533, which shows all its arrangements in detail.

We notice the following points: The wooden cistern or hutch is decidedly longer than usual, for the purpose of subjecting the charge to a larger number of strokes of the piston, and consequently assuring a more careful washing; the sieve supporting the charge is slightly inclined; the area of the surface of the floating piston, which is half the size of that of the hutch; the large size and the arrangement of the space in which the clay or slime collects, which enable it to be drawn off quickly at long intervals without interrupting the operation, &c.

The arrangements adopted for assuring a regular feed, and the continuous automatic discharge, are also shown.

The unwashed coal is fed on regularly by a roller revolving below the hopper, and falls in a shower at one end of the hutch, where it is wetted immediately without having an opportunity of forming into clots or balls, which are very injurious, as we know, to the separating process.

Under the influence of the slight inclination of the sieve, and also in consequence of the pressure of the heap that collects under the roller, the stuff gradually moves along, and finally reaches the other end. The pure coal falls over the end into a transverse

launder, and is carried away by an endless screw, whilst the shale passes through an opening situated a little above the sieve, which in consequence of the weight of the charge, and an effect analagous to that of communicating vessels, permits a continous outflow of stony matters, whilst at the same time a bed of an inch or two deep always remains upon the sieve.

The opening, which can be regulated by a hatch, leads to a second compartment divided by a partition into two parts: the first, in which the work of separation is continued to a certain extent, is intended to extract a small proportion of coal with stone adhering to it, which is lifted out by a shovel, and submitted to a second washing by itself; the second, into which nothing but pure shale escapes, is emptied automatically by a bucket-elevator.

The output of this washing machine, which, it should be remarked, discharges all its products continuously and automatically, is 25 or 30 tons a day; it works at the rate of 30 to 33 strokes of 1½ to 2 inches (4 to 5 cm.) in length per minute, and requires merely enough water to replace that which is carried away by the wet products.

(750) The Grand-Combe washing machine differs considerably from the preceding one, and at the same time deviates from the original type in regard to several particulars.

As shown in fig. 534, it consists of a large square wooden cistern, 4 ft. 6 in. ($1.^{m}35$) on the side, provided with two metallic sieves, between which lies a bed of coarse gravel about 10 inches (25 centimetres) thick, the action of which we shall consider further on.

At the back of this cistern there is a compartment about half as wide, and of the same length, as the one containing the sieve; the two communicate with each other at the bottom. The smaller compartment serves as a working-barrel for a piston, not floating, as in the preceding case, but worked by an eccentric placed above, and not shown in the figure.

As in the case of the preceding example, the piston has a play of about ⅜ inch (1 centimetre) all round, so as to make it work easily, and at the same time to lessen the effects of suction upon the charge lying on the sieve.

Lastly, there is another box in front which receives the washed coal as it flows over.

The operation of washing is performed in the following simple manner:

The screened coal is fed on gradually by means of a door or hatch, which can be raised or lowered at pleasure, and which at each stroke of the piston allows a certain quantity to sink down on to the head end of the upper sieve, which has a slight slope.

Whilst the machine is kept supplied in this manner, the washed coal is carried along by the waves caused by the pulsations of the piston, and flows over the tail end into the front compartment.

As in the case of the Molières jigger, a continuous stream of stuff is thus formed from the head to the tail end of the sieve, and during their passage the various substances become separated into layers in order of equivalence under the influence of the repeated pulsations to which they are subjected.

The washed coal is removed automatically either simply by the inclination of the launder, or by a longitudinal endless screw, which conveys it to a storage bin; the shale, on the other hand, remains lying on the sieve, and the jigging is interrupted from time to time for the purpose of shovelling out the bed that has accumulated.

It is necessary in this case to say something about the method of working the piston, which does not return freely to its original position, but is drawn back to it somewhat abruptly by the movement of the eccentric to which it is attached. This would have had the effect of drawing back the water too quickly through the charge, and thereby producing injurious eddies and irregularities of action, if two special arrangements had not been made to obviate this defect. One of them is the insertion of the bed of gravel between the two sieves referred to above, and the other consists in reducing the number of strokes to 12 per minute, and increasing their length to 10 inches (25 cm.), so that, in spite of the resistance of the bed of gravel, the charge is raised effectually, and does not remain motionless on the sieve as was to be feared.

At the Grande Combe this machine is used for washing small

coal of ¾ inch (2 centimetres) and less, containing 16 to 20 per cent. of ash. It produces 12 to 20 tons of washed coal in ten hours, with 5 to 11 per cent. of ash, according as coal with or without dust is treated. It requires 1100 to 1300 gallons (5 or 6 cubic metres) of water per day, and about half a horse-power is sufficient to drive it.

(751) It would be easy to multiply these examples by describing the long series of machines of the same kind which are used for washing coal in the different coal-fields. We might mention more especially the machines of Rexroth, Sievers, &c., employed in Germany and Belgium, the Bradford, Smauch, and other jigs in America and England. But the principle being in every case the same, we need only say that these machines differ from each other by the details of their construction; for example, by the relative arrangement of the various parts, the greater or less use of metal in place of wood, the various mechanical arrangements intended to reduce the amount of hand labour, &c.

Their common character is that the charge lying on the sieve is traversed twice by the water during each complete oscillation of the piston—the first time in an upward direction, when it is raised; the second time in a downward direction, when the water is withdrawn to occupy the vacuum which the piston leaves behind in its ascent.

But these alternate movements of the water through the charge give rise to an important observation, upon which M. Marsaut has recently thrown some light in the following conclusions.

The observation is the following:

If we suppose—what we know to be the case, and what is always apparent in practical working—that each category produced by the classifying machine contains not only pieces of a size corresponding to the difference between the dimensions of two successive screens, but also all the smaller sizes down to that of fine dust, and that in variable quantities, according to the nature of the coal, it will necessarily follow that, when the piston ascends, the water which passes down through the charge in the spaces between the fragments will always draw along with it by suction a certain

proportion not only of heavier particles of shale-dust, but also some of the much lighter dust of pure coal. This sludge will be drawn down below the level to which it properly belongs; and, finally, it will pass through the sieve and become deposited at the bottom of the machine, where sufficient space is always left to receive it.

(752) This *aspiration* or *suction* may produce very variable effects, either on the quantity of sludge, or on the quality of the washed coal.

It is evident, in the first place, that the amount of suction will increase with the size of the fragments and the proportion of granular particles, because the vacant spaces left between them will be larger, the current more rapid, and the outflow more easy. On the other hand, in the case of a coal mixed with a larger or smaller quantity of dead small and dust, the interstices are obstructed to a certain extent; and if the movement of the piston is not too rapid, the return of the water through the charge takes place through numerous small channels of very restricted section, which retard the current, increase the friction of the grains of sludge, and allow only a relatively small proportion of the fine matter to pass into the lower compartment.

The result of this is, at first sight, somewhat paradoxical; namely, that the small coal which contains the largest proportion of dust does not necessarily produce the greatest amount of sludge when jigged, and that granular coal may produce large quantities of it, not only because the dust contained in it can be more easily drawn out, but also because the more energetic action of the suction always tends to produce a larger or smaller quantity on the sieve itself, in consequence of the particles rubbing against each other.

Now if we bear in mind that the coal is generally much more friable than the shale, and that consequently it furnishes nearly the whole of the dust produced by these alternating movements of the charge on the sieve, we shall easily see that the last-named loss is all the more serious, as the sludge to which it gives rise is purer, and yields a smaller proportion of ash.

(753) Whatever may be the total quantity of sludge produced or collected in this way—and it is often very considerable, amounting it may be, to 15 or 20 per cent. of the whole—it will not always have the same degree of importance, and may be of more or less consequence to the mine owner, according to the mineralogical constitution of the coal in question and its intimate structure, which has the greatest influence on its purity.

Indeed, if we have to do with a soft and pulverulent coal, associated with hard shales approaching the nature of sandstones, and coming from a clean seam with firm roof and floor, we may conclude that the shale will be almost always in the form of lumps and not of dust, and that it will consequently not enter to a large extent into the composition of the sludge.

On the contrary, if the coal is granular, and the enclosing rock, or the interstratified ribs consist of soft, friable, or clayey shale, easily brought into suspension in water, the greater proportion of this soft shale and clay will pass into the sludge, whose yield of ash will consequently increase considerably.

In the first case the sludge can be added to the *washed coal*, without greatly altering its mean composition, and it will even be useful if the coal is to be employed for making patent fuel or for coking, because the products obtained will be more compact, more resisting, and of a more marketable appearance.

In the contrary case this mixing is impossible, and therefore the coal contained in the sludge will constitute a decided loss of fuel, for which we get no sufficient compensation.

The consequence of all this is that there is always a certain degree of interest, when jigging coal, in retaining in the mass a certain proportion of the dust. When the dust is pure, we thereby avoid the subsequent operation of mixing; and when it is impure, the object is to allow only the heavier particles to be lost, that is to say, those most contaminated by clay, at the risk of raising the mean percentage of ash a little.

(754) This diminution of the quantity of sludge produced is effected in several different ways.

Independently of the special apparatuses that have been in-

vented for the purpose, and of which we will speak further on, attempts have been made, without introducing any fundamental alteration in the process of jigging, to remedy these losses by altering the details in various ways, either in the mode of treatment itself or in the machine.

The first consists, as we have seen, in taking less care in classifying the coal according to size, or even in certain cases, when the dust is very pure and incapable of altering the quality of the coal much, to omit the classification altogether. This expedient cannot always be resorted to, however; for in changing the conditions of the operation the cleanness of the products is evidently interfered with.

It has also been proposed to avoid the return of the water through the stuff by providing a lateral opening, through which it may flow into a special pipe, and return under the piston by a round-about road.

But the contrivance most generally adopted consists either in allowing a bed of shale of a certain thickness to remain always on the sieve, or even, as we have seen in the Grande-Combe machine, in enclosing this bed between two sieves. The effect of this *safety bed* is not only to regulate the action of the water, and to assure a uniform lifting of the stuff, but also to increase the friction of the liquid, to retard its flow, and to oppose mechanical obstacles to the escape of the particles in suspension.

The influence of the bed of shale on the production of sludge can at once be ascertained when we empty the sludge chambers of jiggers in which the shale is removed at intervals. We are able to distinguish clearly a series of stratified beds passing gradually from pure sludge, formed at the beginning of the operation just after the removal of the shale, to more and more impure sludge, which was drawn through a bed of stony matters, whose thickness was gradually increasing.

Lastly, if we wished to limit the loss due to the sludge as much as possible for any given kind of coal, and a given washing machine, it would be necessary to make a number of experiments with the view of ascertaining the exact number of strokes of the piston necessary to produce the separation, bearing in mind

this fact, which has been taught by experience, that at the end of a certain time, when each particle has fallen into its proper place in the order of equivalence, the movement of the piston has no other effect than to tend to break up the stuff upon the sieve, and consequently to produce a further proportion of sludge, the purity of which increases in proportion as the friability of the coal exceeds that of the shales.

(755) All these expedients hardly succeed in reducing the amount of sludge by more than from 5 to 8 per cent., and there always remains a large proportion, which the mine owner is not willing to throw away, without making some attempt by further washing to save at least part of the useful matter which it contains.

This washing is undoubtedly accompanied with a great loss, but when it is considered that we are operating on stuff which is otherwise of no value, it is evident that it is not necessary to obtain a large return in order to cover, and more than cover, the cost of the labour.

The system first in use depended on the employment of plane tables (*frames*), waterfalls, slime pits, &c. The plan formerly adopted at the Grand-Combe works was as follows:

The sludge was allowed to run directly into a first tank, or was shovelled in, and was then well stirred up by an agitator; the outflow of this tank, holding the sludge in suspension, passed into an inclined trough (*launder*) about 110 yards (100 metres) long, with several small sudden drops in it.

The sand and coarse pyrites settled at the foot of the first drops, whilst the fine pyrites, the fine coal, and lastly the earthy matters or sludge, properly so-called, passed on owing to the velocity of the current. The stream was then cut off and the operation stopped before the fine pyrites had arrived at the end of the trough.

The coaly particles in the meantime had been caught in a second tank, situated at the end of the trough, and the clayey sludge still held in suspension in the water had escaped by a series of holes in one of the sides of the tank, similar to the holes in the tail end of a buddle.

Children were set to clean out the trough with brooms and scrapers, and as soon as it was emptied another washing operation was started.

The stuff operated on contained at most 50 per cent. of pure coal, and it yielded 35 per cent. of washed coal, with 7 to 9 per cent. of ash, and at the time this result was considered as very satisfactory.

(756) This system, and similar ones depending upon the use of slime pits, are being gradually abandoned nowadays, or, at any rate, there is a tendency to combine them with the use of jiggers of various kinds, which treat the stuff either directly or after it has settled systematically in the depositing pits.

These jiggers, which are all derived with hardly any perceptible modification from the Hartz jiggers, differ from them only in their inverse mode of action, in this respect, that it is the refuse and not the valuable matter which traverses the bed of particles of shale or quartz placed on the sieve, whilst the washed coal, more or less deprived of earthy matter and pyrites, passes over and runs into large ponds, where it settles, and is collected.

We shall not again describe the precautions, already referred to in speaking of metallic ores, which conduce to the satisfactory working of the apparatus, viz., regular feed, thorough suspension of the stuff in water from the commencement, &c. We need only say that a jigger of this kind, working at the rate of 100 to 120 strokes per minute, is capable of treating 6, 7, or even 8 tons of stuff per day, with a consumption of 44,000 gallons of water (20 cubic metres), and of reducing the average percentage of ash to 8 or 10 per cent.

(757) Notwithstanding the considerable improvement introduced into the system of washing sludge by the method we have just described, it may be said that, either on account of these machines being somewhat delicate, or because they can treat only sandy particles, and allow the whole of the fine dust to escape in the black water, and so fail to prevent loss altogether, there is still something wanting in the dressing of coal. The question cannot

therefore yet be considered to be solved from an industrial point of view.

Besides, if we reflect that the adoption of the Hartz jiggers is comparatively recent, we cannot be astonished that the inventive faculties of the constructors have been busily engaged ever since their introduction in trying to reduce these losses by means of various contrivances, modifying for the most part, in greater or less degree, if not the principle, at all events the accessory arrangements, of the piston-jigger.

The traces of these attempts are indeed discernible in a large number of machines, each of which has come into favour in turn, such as the washing-machines of Bérard, Revollier, Forey, Rivière, &c.; as well as in the washer for dead small of M. Évrard, whose earlier crown washing-machine for coal of ordinary dimensions, which was very ingenious and original, but too costly to keep in repair, works, on the other hand, in identically the same manner as the piston-jigger.

The principal object of all these washing-machines is not only to pass a comparatively greater quantity of stuff than the jigger, but also to hinder the return of water through the charge, and consequently the carrying away of the fine coal.

It would take too long a time, and besides would not be of sufficient interest, were we to attempt to describe all these various types. We shall confine ourselves to Bérard's apparatus, which was formerly one of the most widely employed, and of which there are several examples still in use.

(758) The whole of this machine, as it was first designed and constructed by its inventor, consists of the following parts (fig. 535):

1. A picking and crushing department, not shown in the figure, comprising two screens intended to separate the large coal, which is picked by hand, and the dust, which proceeds directly to the washing-machine. The intermediate variety passes successively between two pairs of fluted rolls, and then falls into a pit large enough to store a certain quantity between the departure of one truck and the arrival of the next.

2. The machine itself consisting of two distinct parts—one for sizing, the other for crushing, properly so-called. We propose to describe these two operations somewhat in detail.

The classification according to size is effected by means of a series of perforated plates one above the other, shaken backwards and forwards at the rate of 150 to 180 strokes per minute. They are fed by a bucket elevator, drawing its supply from the pit in which the crushed coal is stored. In the case of clayey and wet coal, the sizing process can be assisted by a stream of water, which prevents the holes from becoming choked. Although the sizing was somewhat rudimentary at the time machines of this kind were first constructed, it can be carried further without changing the characteristic features of the apparatus. Two categories of stuff are generally produced, sometimes three, each of which is conveyed by a suitably-arranged system of shoots to a separate compartment of the washing-machine properly so-called.

These compartments are neither more nor less than a series of jiggers placed side by side. Each consists of a rectangular cast-iron tank, having one part of its bottom inclined at an angle of 45°, while the rest of it is horizontal. A cylinder cast in one piece with the plate, which forms one of the smaller sides of the rectangle, serves as a working-barrel for the piston of the jigger. It opens into the rectangular tank about the middle of its height, and is enlarged in the bottom at its junction with the flat side, in such a way as to occupy almost the whole width. The object of this arrangement is to make the action of the water uniform over the whole surface of the sieve. The number of strokes, which was too great at first, had to be diminished, and the machine is now usually worked at about the same speed as ordinary piston-jiggers.

We must notice particularly the ingenious arrangements adopted in this apparatus, both for removing the products automatically, and for lessening the amount of sludge carried through and lost.

These contrivances are as follows:

The shale escapes, in virtue of an effect similar to that of communicating vessels, through an opening between a hatch and a flange, which permit it to pass intermittently at each stroke of the piston over the flange, in the same way as happened in the case

of the Moresnet bell-jigger, described in paragraph 686. The height of the lower edge of the hatch above the sieve regulates the thickness of the bed of shale, which acts the part of a safety bed. The sludge which has passed through the perforated plate of the sieve, notwithstanding these precautions, can be drawn off from time to time from the bottom by opening a valve.

The coal is discharged at the other end of the tank, and its withdrawal can be effected in two ways.

In the first, the coal is carried over the edge of the tank by a current of water brought in under the piston, and slides down a tray into a trough, from which it is lifted by a bucket-elevator and loaded into waggons.

In the second, the level of the water is kept as high as the edge of the tank, but there is no current; however, the weight of the coal which is always arriving at the opposite side of the sieve exercises a kind of pressure, which forces a certain portion of washed coal at each stroke of the piston to fall over the front edge of the tank into the trough, whence it is afterwards raised by means of the bucket-elevator mentioned in the preceding case.

(759) When the coal is carried over the edge by the current, the amount of water flowing into the machine must be very considerable. It enters the working barrel below the piston through a pipe specially provided for the purpose. It then serves three distinct purposes; namely, to carry away the coal, to clear the water under the sieve, and to diminish the effects of suction.

The coal passes over an inclined plate perforated with very fine holes; the water drains off and finds its way to settling-ponds, where the sludge is deposited.

The area of the inclined plate, and the number of holes in it, can however be limited in such a way as to permit only a portion of the water to drain off; so that, when the waggons are being loaded, part of the water which remains filters through the coal contained in them, and comes out nearly clear. This operation does not succeed, however, except with certain kinds of hard coal, which produce only a small portion of dust; and with soft and very dusty coals recourse must be had to another plan, as follows:

The perforated plate over which the coal passes is replaced by one without holes, and the trough in front is provided with a hatch and flange, between which a kind of decanting process takes place. The coal and the greater portion of the dust remain at the bottom, and are raised by the bucket-elevator, whilst the water, which holds only the lightest matters in suspension, escapes over the flange. In each bucket of the elevator again a partial filtration takes place, which adds its effect to the preceding one.

If it is feared that, notwithstanding these precautions, too much sludge would still be lost, as in the case of a coal producing very pure dust, the second system is resorted to, the water supply is cut off almost entirely, and the coal is no longer swept over the edge by a stream of water, but simply falls over it as we have seen. In this case there is no opening with a hatch, but the level of the water in the trough is maintained at a uniform height by means of a small side hole, and the water which escapes at this point contains only the lightest particles. The washed coal is removed, as before, by means of the elevator.

According to the statements of the inventor, a machine of this kind can wash 150 to 180 tons of stuff in a day with 10 horse-power.

Such is the essential part of the machine known by the name of Bérard's washer; his portable machine is a precisely similar contrivance with only one tank. As is very evident, and as we have already said, the washer is merely a series of three piston-jiggers placed side by side, and provided with contrivances similar to those we have described in the washing machines of Grand-Combe and Molières for the purpose of diminishing the loss of sludge.

It is, however, necessary to remark that, although we reversed the true order of events by beginning with the description of the machines fitted with all the improvements which have been introduced from time to time, it is nevertheless true that most of the contrivances were first applied in Bérard's machine, and that it is to him we are indebted for the original ideas. Consequently, though very unlike the old hand-washers, Bérard's machine is now distinguished from the improved machines actually in use much

more by its general mode of action, and the relative arrangement of its various parts, than by the ingenious contrivances in its construction which were formerly its distinctive features.

It is for this reason, we believe, that this machine, and all others of the same kind, are bound to disappear before the improved piston-jig, which is simpler, more convenient, more easily erected, and washes equally well.

(760) We shall not say as much of the washing machines which we have still to describe, and which, as we shall see, depend upon entirely different principles and contrivances.

It will be recollected that the oscillating movement of the water in the piston-jigs, and other machines of the same class, does not effect the separation in strict accordance with the laws of equivalence, that is to say, not solely in consequence of the combined influence of density and size; for the numerous and rapid strokes repeatedly utilize the first instants of the fall, and thus give a certain preponderance to the density. We have further seen that the filtration of water through the charge produces a sort of suction, the effect of which has also been studied.

The last washing machines which we are about to describe, generally act, on the other hand, by less distinct or less frequent strokes, and avoid almost completely the suction and the consequent loss of sludge, by entirely preventing the return of the water through the charge. The separation, however, is effected by two perfectly opposite methods.

In the machines which work according to the system invented by MM. Meynier, Coppée, &c., and especially in M. Max Évrard's washer, there is an intermittent, continuous, or oscillatory current of water passing upwards through the charge. In M. Marsaut's machine, on the contrary, it is the charge which falls in still water, being subjected to a succession of drops, properly proportioned to the size of the stuff under treatment. In both cases the results are almost identical as far as the separation is concerned.

This will be apparent from the description we shall now give of of the two last mentioned machines, those of MM. Évrard and Marsaut.

(**761**) *Évrard's classifying and washing machine*, according to the inventor, embodies the various types of washers successively invented by him; but, after what we have seen, it may be considered to differ from them essentially, not only in its arrangements, but also in principle. It is shown in figure 536, which represents a large machine.

It consists of a cylindrical or rectangular tank (the washing tank), 23 to 26 feet (7 or 8 metres) deep, with a sectional area, of 54 to 64½ square feet (5 or 6 square metres); however, these dimensions are by no means fixed, and may vary between very wide limits. It communicates by means of a pipe *t* near the bottom with a second tank (the piston tank) of the same section, but less high, and both are more or less completely filled with water.

At a depth of about 6 feet (2 metres) below the top of the first tank there is a frame covered with a perforated plate, and intended to receive the charge, amounting to about four tons.

As the second tank is hermetically closed, sufficient pressure exerted on the surface of the water contained in it, will make the water pass through the communicating pipe, rise in the first tank, find its way through the holes in the perforated plate, and lift the charge. This action is obtained by means of a current of steam, brought by a pipe to the top of the tank; it condenses at first on the surface of the cold water, but produces the desired effect as soon as this water has been heated to the depth of an inch or two.

A simple three-way cock suffices to admit it or to cut it off, and in this way to produce either an ascending or an intermittent current, or oscillations of any desired amplitude.

The charge having been brought to the top of the tank, the steam cock is opened, and the water is made to rise to a height of about three feet above the perforated plate. The charge is then tipped in, and as it has to pass through a grating it is distributed evenly and becomes wetted more effectually.

An extra amount of steam is then turned on and cut off several times in succession by means of a special cork. The effect of the resulting pulsations, added to that of the ordinary ascending current, assists the separation.

When the water reaches the top of the vat, the steam is shut off, the exhaust is opened, and the operation is at an end.

In order to withdraw the products, it is necessary to allow the slime to settle for a few minutes; the sieve is then raised by means of an hydraulic piston. The water which is retained on the top of the charge by the impermeability of the sludge runs over, and finds its way to settling ponds, whence it is brought back to the machine. During this time the charge continues to rise, and finally arrives at the upper end in a perfectly compact condition. It is then cut off in horizontal layers by means of a mechanical slicer.

The thickness of the slices varies with the quality of the coal, and should be fixed beforehand by the results of analyses of the products of several experimental operations. The highest slice contains the finest particles more or less pure, and the lowest consists of shale and stones. These two products are distinctly marked.

This is not the case, however, with the intermediate portion.

As can be easily understood, this part ought to consist of small grains of shale mixed with large like-falling grains of coal, in variable proportions according to the nature of the raw coal treated. This mixture, which is more or less clean according to the quality of the unwashed coal, cannot always be considered as a finished product, and ought then to be subjected to a further treatment, in order to diminish the proportion of shale which it contains. This is carried out usually in practice by means of the crown washer already referred to, which is an almost indispensable adjunct of the classifier. We shall not describe it, however, as it belongs to the general category of piston-jigs.

This mode of procedure appears to us to be somewhat improper.

In fact, although density has a somewhat greater influence than size in the piston-jigs, as we have just pointed out once more, it is nevertheless true that to feed the machine with stuff classified according to the equivalence instead of according to size is decidedly objectionable.

It is evident, admitting the separation according to equivalence in Évrard's tank by means of the ascending current to be perfect

and complete, that we might and ought to obtain an improved result by re-washing the product in a piston-jig; but that this improvement will always be less marked and less easily effected than when the stuff is well classified according to size.

Although the same principle is applied in the case of metallic ores when treating fine sand and slime by ascending-current classifiers, it should be recollected that it is only used by stress of circumstances, and that the effects of its theoretical imperfection are pointedly felt in practice. But as this method of procedure is no longer obligatory here, in consequence of the greater size of the stuff treated, it appears to us to constitute the principal defect of M. Évrard's system. However, the apparatus is distinguished by great simplicity, easy working, and ingenious details of construction, as well as by the use of the steam piston, which is entirely new.

The amount of coal which the washer will treat varies with its dimensions, and is about 200 tons per day in the case of a machine of the size shown in the figure.

(762) M. Marsaut's washing machine acts, as we have seen, in an inverse manner to the foregoing one.

It is a kind of cage or basket with a sieve bottom, which is caused to make a series of drops of an inch or two at a time in still water. During these drops each particle of the charge arranges itself at the same level as the other particles which are like-falling to it, without being disturbed by any kind of accessory action. At the end of the operation the washed stuff is divided into horizontal layers, consisting of pure coal, refuse shale, and a mixture of the two which has to be re-washed.

As the dimensions of the cage are comparatively large, it has been necessary, in order to render it easily handled, to have recourse to mechanical arrangements which well deserve attention.

The machine consists of the following parts (fig. 537):

1. A wooden tank of rectangular section, open at the top, and closed at the bottom by a horizontal partition, provided with sliding doors, which separates it from a reservoir in which the sludge is deposited, and from which it can be discharged almost in a state of dryness without interrupting the operation of washing.

2. An iron cage working in guides, the bottom of which is like an ordinary jigging-sieve; the sides consist of three separate horizontal sections, like drawers without bottoms, which can slide upon each other in such a way as to cut off the charge at their level, and cause it to fall into hoppers provided for its reception. The cage hangs at the end of a rod attached to a piston that can work up and down in a long cylinder filled with water under pressure.

3. A lateral overflow reservoir, which prevents great variations in the level of the water while the cage is being charged; underneath it there is a return pipe provided with a floating valve, which allows water from above the cage to pass down and enter the space below during its ascent, but prevents the water from passing in the reverse direction during its descent.

4. A suitable series of hoppers for charging the raw coal, and receiving the washed products.

The operation is performed in the following simple manner, and requires only one boy to look after it:

The charge, which consists of three, four, or even five tons, having been previously tipped into the feeding hopper, and the cage being at the top of the tank, which is already filled with water, the door of the hopper is opened, and the charge falls into the water in the form of a shower, so that it is all well wetted. By opening the escape cock of the cylinder, the workman then causes the cage to give two or three longish strokes, in order to distribute the charge properly; and by means of the same contrivance, which is rendered very exact by a water gauge, whereby the length of the drop can be regulated from $\frac{3}{4}$ inch to 8 inches (2 to 20 centimetres), he causes the cage to drop in a similar manner, a number of times in succession, the stroke being proportioned to the size and nature of the coal under treatment.

Lastly, when the cage has reached the bottom, it is allowed to stand still for a few moments in order to give time for the coarsest of the fine and light particles, which fall slowly, to settle upon the charge.

The operation is then at an end, and nothing remains but to collect the products.

For this purpose the cage is raised three times in succession,

and at each stage a hydraulic piston, placed behind the apparatus, pushes out the drawer which has been brought up to its level, and skims off, first, the pure coal, secondly, the mixed stuff, and lastly, the shale, each division falling into the special hopper intended for its reception.

During the ascending movement, the water contained in and above the cage cannot penetrate through the charge on account of its great thickness, but passes through the pipe, and returns under the sieve, so that none of it is lost, except that part of it which is carried away in the washed products.

A machine of this description, having the dimensions shown in the figure, will wash 120 to 150 tons of coal per day. The power expended upon the accumulator does not exceed 1 H.P.

(763) It is difficult to produce in a more simple and practical manner the conditions of a fall in still water, which at the same time eliminates all the causes that tend to disturb the result, and for this reason we should expect to realize in practice exactly and mathematically the effects indicated by theory.

With the same qualities of coal we ought to get the same results as in Évrard's machine, even a little better defined perhaps, as the conditions under which the operation takes place are in some degree more natural.

But although in principle these results ought to be the same, they have hitherto been very different in practice, because of the way in which the machines are employed.

M. Évrard usually delivers the stuff to his machine without any previous sizing, and causes it to effect a first classification according to equivalence. After this he separates the fine parts and the coarse shale, and subjects the intermediate parts to another operation very little different from the first. This is evidently a mistake.

M. Marsaut commences in a more rational manner, by a careful classification according to size. He delivers nothing to his machine that has not been suitably sized, in order to effect a final separation by density instead of equivalence.

It may be said, therefore, that the great difference which,

according to our way of thinking, exists between the two methods of treatment is due much more to the manner in which they are conducted than to the qualities of the machines themselves. But sufficient experience has not yet been gained with them to enable us to express a definite opinion upon their respective merits.

(764) Such is a brief account of the principal machines employed in washing coal.

If we compare the two extreme terms of the series, and take into account the principal points that modify and distinguish their results, we may make the following remarks, which briefly sum up the foregoing observations.

In the first place, the piston-jiggers, which classify more perfectly than any others as regards separation according to density, always produce a certain considerable amount of sludge, in consequence of the water returning through the charge; and although we have seen that this loss can be reduced somewhat by means of various contrivances, it cannot be altogether avoided. Moreover, the mode of action of this machine allows us to deviate somewhat from the strict rules of classification according to size, and for two reasons: first, the rapid succession of pulsations causes frequent repetitions of the initial period of the fall, and so ensures a certain preponderance to the influence of density; and secondly, the suction eliminates a certain quantity of dust, which contains a larger proportion of heavy clayey matter than the raw coal. This diminishes the percentage of ash in the product.

On the other hand, the machines in which the water does not return through the charge, with longer and less frequent pulsations or drops, such as the Évrard and Marsaut washers, when worked in the usual manner, ensure an exact classification according to equivalence without sensible loss of sludge, and consequently yield results which are in exact accordance with theory. The greater or less distinctness of the results will depend upon the nature of the substances operated upon, and particularly upon the degree of exactness with which they have been classified according to size, and the principal action will not be disturbed by any accessory effects.

The mixed varieties of washing machines, which exhibit the characteristics of the preceding ones to a greater or less extent, give results which vary according as they approach more or less closely to the one type or the other.

(765) If we reflect upon these facts, we shall be in a position to determine what method of treatment appears *a priori* to be the most suitable for a given quality of coal.

The greater or less importance to be attached to classification according to size will depend first of all on the peculiar constitution of the coal, and the more or less close manner in which the pure coal is intermixed with the shale. If the mixture is so intimate that even small fragments contain both shale and coal, it will sometimes be necessary to have recourse to a preliminary crushing in order to subdivide the stuff properly. But this crushing should not be carried further than is strictly necessary in order to separate the various elements of each fragment.

The sizing should be performed according to the known laws, and be pushed more or less far according to the specific gravity of the constituents of the raw coal, which vary with the nature of the seams from which it is obtained.

These are strict rules which ought never to be departed from in practice.

This being premised, we have now to arrange how each category is to be washed separately, and this part of the problem is somewhat more complicated.

It is necessary to remember that, however well the particles have been sized, a certain quantity of dust always remains mixed with them; we must consequently distinguish the cases in which the dust is pure from those in which it is impure.

We will assume, in the first place, that the classification according to size has been carried out thoroughly well. As the dust is found almost solely in the upper part of the charge in Évrard's and Marsaut's washers, while, on the contrary, it is carried away altogether in the piston-jiggers, it would be best to employ the former class of machines when the coal dust is pure, and the latter when it is impure, and in this case subject the resulting sludge

to subsequent treatment, in order to extract as much as possible from it.

On the other hand, if for any reason whatever the classification according to size cannot be effected carefully enough, Évrard's and Marsaut's machines, which are very imperfect with impure dust, will give indifferent results with ordinary dust, but satisfactory results with pure dust; so that, although we can dispense with the employment of piston-jiggers in the last case, we seem driven to employ them in the two former, on condition that the sludge is re-washed.

Lastly, the circumstances under which combined washing machines can be employed will depend upon their particular mode of action, which makes them participate to a larger or smaller extent in the properties of the extreme types.

We must admit, however, that these are not altogether the conditions in which the various machines for washing coal are employed; but the conclusions which we have drawn from an examination of them appear to us to be the most rational, and to be those that should guide the engineer who has to turn his attention to this delicate branch of the art of mining. It was M. Marsaut who first pointed them out, and it is also to him we must give credit for the new classification of coal-washing machines which we have adopted, as well as for the important remarks regarding their practical application.

(766) It would be undoubtedly very useful to add to the technical descriptions of the foregoing pages a few observations respecting the cost of washing, as well as some examples of the difference in the percentage of ash—in the raw material and in the washed product.

But these data vary so much with the quality of the coal, and the conditions under which the work is carried on, that it is very difficult to give any exact figures. We may say, however, in a general way, that for raw coal having a yield of ash varying from 10 to 12, and even from 25 to 30 per cent., the degree of purification will vary with the percentage of impurities, and can be pushed further and further as the quality of the coal improves.

The amount of ash in the washed coal will generally vary between 6 and 15 per cent.

The cost of washing will also fluctuate greatly, according to the degree of purity obtained, the nature of the machines employed, and the mechanical arrangements of the washing establishment, of which we shall speak further on. It will be between $2\frac{1}{2}$d. and 1s. (0 fr. 25 and 1 fr. 25) per ton, which is a very striking difference for substances that are handled in such large quantities. In any given case the calculation can easily be made beforehand, and of course due allowance must be made for the original purchase of the plant, as well as for its depreciation.

(767) We must now take into consideration the fact that the mere choice of a good machine, suitable to the nature of the coal to be washed, does not of itself suffice to constitute a good system of dressing, but that besides this we should be careful to arrange the washers conveniently, and to provide them with every possible mechanical contrivance for ensuring economy in handling the coal, on account of the large quantities that have to be dealt with.

It is evident that the arrangement of these accessory appliances, which occupy an especially important position in this case, may easily cause the cost of the various handlings, not including the washing, to vary considerably, and be even four times as great in one case as in another. Their arrangement requires, therefore, to be studied with great care in planning a washing establishment.

For this reason we think it well to add descriptions of a certain number of establishments of this kind to the preceding observations, for this is the only way of showing how the subject should be studied.

We have selected examples which all present certain useful peculiarities.

(768) The first and most simple is that of the Grand-Combe.

The works comprise a large number of piston-jiggers, identical with those described in paragraph 750, placed in a row in an open shed, represented in section in figure 538.

The waggons of small coal coming from the mine arrive on a platform about 10 feet (3 metres) above the level of the jiggers, and are tipped on to fixed screens with bars ¾ inch (2 cm.) apart. The part which passes through between the bars falls into large hoppers placed underneath, the remainder is picked by women and children.

The hoppers feed the small to the washing-machines in the manner already described, that is to say, by means of a sliding hatch or shutter, which partly dips into the charge. The washed coal which has passed into the overflow-launder is conveyed by an Archimedean screw, which serves four jiggers simultaneously, to a pit, which likewise receives the products from four other jiggers situated on its other side (fig. 538 *a*). This convenient arrangement of bringing together the products of eight jiggers to one point enables various qualities of coal to be collected successively. At first, immediately after the removal of the shale from all eight jiggers we get very pure coal, *i.e.*, coal with a small percentage of ash; whilst afterwards the amount of ash in the washed coal goes on increasing until it reaches the normal percentage. We have thus a ready means of satisfying the various requirements of the consumer.

A bucket-elevator lifts the washed coal out of the pit and loads it into waggons, while the shale is, as we have seen, removed from time to time and thrown away.

An establishment of this kind has the advantage of great simplicity, and of being easily enlarged by lengthening the shed and adding more jiggers successively as it becomes necessary to increase the output. But it causes the operations of picking and screening to be too scattered, as they have to be carried on above each jigger, thereby greatly increasing the amount of manual labour. Moreover, this plan of treatment has the good and bad qualities due to the exclusive use of piston-jiggers, which we will not again specify, and assumes that the quality of the coal is so good as to enable us to dispense almost entirely with a classification according to size, which in this case is a very rudimentary operation.

(769) Systematic sizing begins to be much more clearly defined

in the Molières works, belonging to the Bességes Coal Company. The coal is washed by modified Bérard machines and piston-jigs.

The mixed coal (*through-and-through*) coming in waggons from the mine, is discharged by a hydraulic tipping machine into a trommel consisting of two screens, end to end, which divide it into three sorts:

1. Eggs of 1½ inch (4 centimetres) and upwards, which fall into a small waggon, in which they are raised by a lift to the picking-floors, and they then go to the market.

2. Nuts of 1 to 1½ inch (2½ to 4 centimetres), which are raised by the same lift to a modified Bérard washer, not represented in the figure.

3. Small of 1 inch (2·5 centimetres) and under, which is conveyed by an endless band to a bucket-elevator, by which it is raised into an upper hopper, whence it is carried in waggons to the washing department.

The washing establishment contains a series of six washing machines, such as were described in paragraph 749.

They are erected upon a platform above the ground, which is a very convenient arrangement, as it insures a better preservation of the machines, and facilitates the removal of the sludge, without its being necessary to touch the sieve, which remains fixed. It also enables the shafting of the excentrics to be placed under the platform, so as to hide the whole of the mechanism, leaving a free and untrammelled approach to the tank, and the workmen can thus regulate the operations with the shovel if necessary, as in the case of ordinary jiggers.

The shale and the washed coal are lifted by bucket-elevators, which load them into hoppers closed by a single sliding door, under which the waggons are brought to be filled; the shale is sent to the rubbish tip, and the coal to the market. One bucket-elevator serves for two washers.

With about 20 horse-power these works can treat 300 tons of raw coal a day, giving a quantity of egg-sized lumps, and from 150 to 180 tons of washed small. If the movements of the stuff are followed from the moment it reaches the works in a raw state until it leaves it as marketable coal, or as shale, it will be seen

that only the pieces of mixed coal and shale, which form a very small percentage of the whole, are taken out by hand. All the other operations are performed by machinery, except of course the tramming of the waggons, which can all be done by one man.

These conditions are evidently favourable in an economical point of view.

(770) The works of Roche-la-Molière, belonging to the Firminy Mining Company, and represented in fig. 540, may be taken as another example of a coal-washing establishment worthy of notice. It is here that M. Évrard's machine has been erected very recently under the best conditions.

All the small that has passed through a $1\frac{1}{8}$ inch screen (3 centimetres) is collected and mixed in a large pit, whence it is raised by a bucket-elevator to the highest storey of the works, where it is separated by trommels into three classes.

The *nuts*, which are comprised between $\frac{3}{8}$ and $\frac{3}{4}$ inch, or $\frac{3}{4}$ and $1\frac{1}{8}$ inch (1 to 2 or 2 to 3 centimetres), are sold either directly or after they have been washed in a machine of the old-fashioned type. All below the size of $\frac{3}{8}$ inch (1 centimetre) is passed on to one of Évrard's washers.

We may remark in passing that the necessity of sizing has been appreciated here, and that it has been considered impossible to dispense with it. Under these conditions the objections we made from this point of view to the Évrard system naturally fall to the ground.

We shall not again refer to the details of the washing which we have already described, and we shall only say that by a very ingeniously-arranged distributing-cock the stuff coming from the washing tank and divided by the cutter can be sent in any one of five different directions, corresponding to the five classes of the washed stuff.

1. *The water containing dust* is conducted to a settling tank, and thence to a cone, where the water filters out from the sludge. The latter falls into a pit, and is raised up by a bucket-elevator and added to the washed coal.

2. *The washed coal* is pushed into a hopper, drained and mixed

upon a table, and tumbles down a shoot into a Carr's disintegrator. It is then raised by a bucket-elevator into very large chambers, where more water drains off, and it is at last taken off to the coking ovens.

3. *The mixed stuff*, consisting of fragments of coal intermingled with fragments of shale, is pushed into a shoot and re-washed by a circular washing-machine on Évrard's old system. The observations we made previously as to the disadvantage of preparing for the washing by a classification according to equivalence hold good very decidedly in this case.

4. *The composite stuff*, that is to say, pieces consisting of coal with stone adhering to it, is sent to a Carr's disintegrator, and after having been crushed falls into the large pit containing the raw coal.

5. *The stones* are thrown away. Classes 3 and 4 are not made when coal with 10 per cent. of ash is considered sufficiently clean. The upper slices alone are taken off in this case, and the mixed substances are left in the vat during several operations.

Though these works are well worthy of notice as regards the mechanical and completely automatic transport, they have the defect of being somewhat complicated and excessively expensive to erect.

(771) The screening process, which has assumed more importance in the two last examples, is carried very much further at the Bességes works, where M. Marsaut's new washing-machine (fig. 541) has been erected.

The raw small coal arriving from the mine at the level of the trommels is delivered to them by means of a hydraulic tipping machine, which tips it into the feeding hopper. These trommels are two in number. They have an inside screw and two screens, one outside, the other inside, of 3 feet 3⅓ inches and 3 feet 11¼ inches (1 metre and 1.^{m}20) respectively in diameter, and 5 feet 9 inches (1.^{m}75) in length. They divide the stuff into three classes:—

The first is composed of the pieces that do not pass through the first screen, and consists of the eggs above 1½ inch (4 centimetres). It is divided by a screen with bars into large eggs above 2 inches (5 centimetres), and small eggs of 1½ to 2 inches (4 to 5 centi-

metres). The former are at once picked by hand on an ordinary table adjoining the screen, and are divided into clean coal, coal adhering to shale, and stones. The latter are raised by a lift to a special picking shed, where they are sorted in the same way.

The second class is composed of the intermediate size, which has passed through the meshes of the inner screen without passing through the outer. It consists of nuts of $\frac{3}{4}$ to $1\frac{1}{2}$ inch (2 to 4 centimetres), which are raised by a lift to the top of the hopper for feeding the Marsaut washing-machine, intended specially for treating them.

Lastly, the third, which has passed through both screens, is divided by a shaking screen into little nuts of $\frac{5}{8}$ to $\frac{3}{4}$ inch (15 to 20 millimetres), and into small containing everything under this size.

Both are raised by the hoist, but while the little nuts go to the Marsaut machine, the small is treated by some of the old piston-jiggers, which were put up here more than thirty years ago.

These works, which are intended for treating 700 to 800 tons of raw coal per day, require about 15 horse-power for the trommels and force-pumps, 12 horse-power for the hoist, and about the same amount for the old-fashioned jiggers. The work is therefore done in a very simple, fit, and particularly economical manner.

The following points deserve special notice:

1. The automatic discharge of the waggons into the trommels.

2. The manner in which a fairly complete classification into five different sizes is successfully effected in a relatively confined space.

3. The care with which the sizing machinery is surrounded by an outer ease, which keeps back the dust, and prevents it from flying about outside.

4. The general system of having large hoppers, which give a certain amount of elasticity to the operation of screening.

5. The judicious treatment, based upon the observations already set forth, of the various sizes in machines which are really suitable to them.

The care which has been bestowed upon the various details of this remarkable establishment renders it an extremely interesting subject of study.

(772) We shall conclude with some particulars about an establishment which has no equivalent in France, but which from its vast proportions, and the particular manner in which it has been arranged, deserves at the least a short description.

We refer to a great *breaker*, or establishment for the mechanical preparation of anthracite. Fig. 542 represents a general outline of the establishment that has been erected under the supervision of Mr. W. Eckley Coxe in Pennsylvania, to whose kindness we are indebted for the drawing. It is a large wooden building, with upright posts 12 or 14 inches (30 to 35 centimetres) square, supporting horizontal beams of the same dimensions, properly braced together in the angles; the sides and roof are made of planks.

Part of the building consists, as is usually the case, of an inclined plane, which forms the prolongation of an inclined pit (*slope*) sunk along the dip of the seam of coal. The underground incline has one or two lines of railway, and the ordinary winding engine draws the waggons up to the level of the tipping machines, which are situated at the top of the breaker.

If we now suppose the coal to be tipped (*dumped*, U.S.) at the highest part of the building by these machines, which are only represented by their axes so as to simplify the figure, we can easily follow the course pursued by the coal from the moment it passes over the bars of the first screen to the moment when it emerges into the different hoppers (*pockets*, U.S.), where it is stored before being loaded to be sent away.

We see that during its course it traverses a series of screens with wider or narrower spaces between the bars, then crushing rolls, and finally trommels, where it undergoes a very exact and methodical classification according to size. This constitutes the distinctive character between this system of preparation in which the amount of washing is small, and the system usually employed in France where washing is the principal process.

It will be understood that this difference in the manner of procedure arises from the nature of the coal, which is essentially clean, compact, not friable, and almost useless when in the form of dust.

It will be especially remarked in this figure that the coal travels down automatically from the top of the breaker until it arrives in the hoppers. This is effected by means of suitably-arranged shoots (*chutes*, U.S.), on each of which the coal is carefully picked by hand as it passes along. This method of procedure necessitates a building of considerable height, but at the same time it is important to restrict the height as much as possible in order to avoid or lessen the falls, which are always mischievous.

The general progress of the coal is indicated in the accompanying table, which enables us to follow the details of the operation better than any description could do.*

* For another description of the Drifton "breaker," see *Engineering*, vol. xxxvii., pp. 164 and 311, London, 1884.—*Translators.*

CHAPTER XXVI.

ORGANIZATION OF THE WORK.

(773) Three methods:

α. By the day.
β. By piece-work.
γ. At a fixed price per ton.

α. Careful execution obtained by *supervision*, delicate work, unforeseen events, trustworthy men.

β. Supervision and relations with the workmen rendered easy, advancement in wide faces, haulage, &c.

γ. Economical and rational system, which should be generally adopted. It engages the personal interest of the men.

Several methods:

Letting the whole mine on contract.
Small contracts.

The second system is more moral and more satisfactory to the individual workmen,—more economical but less convenient for the owner.

The first system may be very dangerous under certain conditions; inevitable waste; remarkable examples which could be cited.

Genuine contracts; fixed prices.

Regular entries of the day's work; time-books to be regularly kept; an account to be kept of the manner in which each day or part of a day is devoted to a given kind of work, which forms a definite heading in making up the cost price.

Materials.—The general store carried on strictly, nothing to be

taken away from it without a written order, given by a responsible agent, &c.

Maintenance and repairs.—These should always be charged to the store's account.

Every day and part of a day employed for these purposes, and everything supplied from the workshops for carrying on the work, is to be charged under a special heading in the cost sheet, and everything for the workshops as a new order or as maintenance.

Cost of production.—This should be constantly watched with the greatest care, and should be determined monthly with as little delay as possible.

For that purpose it is important to adopt the system of having fixed prices. Numerous reasons for doing so.

Fixed prices even for the general expenses.

Classification into		cost of labour	Total A.
„	„	cost of materials	
„	„	general expenses	
Classification into		breaking down	The same total A.
„	„	timbering	
„	„	hauling	
„	„	winding	
„	„	stowing	
„	„	sundries	

Keep down the item of sundry charges.

Important observation.—The reduction of the cost of production to a minimum should not always be the sole consideration. The really important point is to keep the difference between the receipts and the expenditure as high as possible. Thus in the case of coal, for example, we might save in the operation of picking and lose in the selling price.

The substances difficult to remove may be left behind.

We may dress ores in a summary manner and obtain a marketable product cheaply, but the more we concentrate the more we lose.

This consideration is very important.

Distinction between the ordinary working cost and the cost of first establishment or additions to it (*capital account*).

This is a delicate distinction of which no unfair advantage must be taken. In every case a charge should be made for the rapid redemption of the capital.

Distinguish an alteration from an addition.

Reduce the value of land to its selling price, buildings to their value when pulled down, steam engines to their selling value, and special machinery to its value as old iron.

The cost of shafts and other mining works should be redeemed within the time during which they are in use, and in estimating beforehand the length of their useful existence care should be taken to reckon it as comparatively short.

This is the best means of avoiding self-delusion as to the financial condition of a mining enterprise.

CHAPTER XXVII.

GENERAL OBSERVATIONS ON THE CONSTITUTION OF MINING COMPANIES.

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APPENDIX.

DESCRIPTION OF THE PLATES.

Plate XCV.—Figures 480 to 484.

Fig. 480.—No. **623.**—Hammer for spalling the large stones. It has a stiff handle of ash or hazel-wood, 3 feet 7 inches ($1.^{m}10$) long, and weighs 3 pounds 5 ounces to 4 pounds 6½ ounces ($1.^{k}5$ to 2 kilogrammes). Smaller hammer for further reducing the size of the stones; it weighs about 1 pound 1½ ounce ($0.^{k}5$), and has a flexible handle about 2 feet 3½ inches ($0.^{m}70$) long.

Fig. 481.—No. **623.**—American stone-breaker, or breaker with jaws. This machine consists of a fixed vertical or slightly inclined jaw A, and a movable jaw B, receiving its motion from a *pitman* D through the medium of the toggle-plates CC′. When the jaw B is pressed against the jaw A, it breaks the stones that are thrown in at O; the jaw is drawn back by the spring R.

The wedge E, regulated by a bolt and nut F, permits the lower opening, through which the broken substances fall out, to be enlarged or diminished at pleasure, and consequently enables us to vary the size to which the stones are broken.

A heavy fly-wheel V serves to store up the energy of the motor during an entire revolution of the shaft, although the resistance is intermittent.

Fig. 482.—No. **626.**—Cobbing-hammers of various kinds.

a represents the commonest kind in use, employed for nearly every kind of ore.

b is used for shaly ores, which split into slices.

c for concretionary ores.

d is a kind of scraper for detaching rich particles of ore adhering to pieces of veinstuff, or *vice versâ.*

Fig. 483.—No. **632.**—This figure represents the Corphalie Trommel, which is both a washing and sizing machine.

The part which serves for washing consists of two truncated cones connected at their bases AA. The first has a very narrow opening, and receives the ore, together with a large quantity of water, from a hopper, whilst the second cleans it with the aid of spikes riveted to the sheet-iron inside.

From A the stuff passes into B, and then into C.

In B the clayey mud and the finer particles of ore pass through small holes $\frac{1}{8}$ inch (3 millimetres) in diameter.

In C the remainder passes into a screen with bars $\frac{1}{2}$ inch (13 millimetres) apart. The ore that passes over falls into the shoot C, where it is picked by hand, whilst the ore that passes through goes by the shoot D to the sizing-trommel EF.

This sizing-trommel consists of five cylindrical screens made of perforated sheet-iron, with the holes increasing in diameter. They divide the stuff comprised between the sizes of $\frac{1}{8}$-inch and $\frac{1}{2}$-inch (3 and 13 millimetres) into five classes, which fall into the troughs *ee*, where they are collected.

Fig. 484.—No. **634.**—This figure represents a washing-trough, intended for washing iron ores.

The machine consists of a semi-cylindrical trough, with a revolving axle A in the middle provided with arms. The arms stir up the ore, detach and dilute the clayey particles, and bring the cleaned ore to the end, where it is discharged.

The trough is lined with planks, covered over with plates of cast-iron. It is closed at both ends by semi-circular iron plates, one of which has an opening at its lower edge, through which the ore passes to the bucket-wheel B.

The ore is stirred up and at the same time driven towards the end of the washing-trough by longitudinal bars fixed obliquely to the generatrices of the cylinder, and fastened to the shaft by means of bosses and radial arms.

This washing-trough has been constructed from a design by M. Salzard.

Plate XCVI.—Figures 485 to 489.

Fig. 485.—No. **638.**—This figure represents a pair of cast-iron crushing rolls.

The first is driven by a revolving shaft, and the other turns by the friction of the ore, which is caught and crushed between the two rolls.

In this way no breakages of toothed gearing need be feared; and the wear is uniformly distributed over the surface of the rolls, as new parts are constantly coming opposite to each other in consequence of the relative slipping which always takes place.

The springs which push against the bearings of the *driven* shaft should be noticed. They are made of india-rubber rings, separated from each other by discs of steel. They allow one roll to move a little away from the other, in case a very hard fragment of veinstuff or other foreign substance should fall between them; but they always exert sufficient pressure for crushing the ore properly.

The simple method of feeding the crushed stuff to the rolls by means of a roller placed under the hopper will also be remarked.

FIG. 486.—No. **639**.—This figure shows how we can deduce the minimum diameter of the rolls from the diameter of the pieces to be broken.

FIG. 487.—No. **642**.—This figure represents an old-fashioned type of stamps, constructed almost entirely of timber.

Each battery consists of three heads lifted alternately by the cams of a revolving axle, and each stamp is composed of a lifter of fir, beech, or oak timber provided at the bottom with a head of hard cast-iron.

These stamps drop in the *kofer*, or mortar, where the stuff to be broken is lying, and break it smaller and smaller, until it can pass through a grate or screen placed in front.

The stuff is delivered to the stamps by an inclined tray, which has a backward and forward movement, and at each blow lets a certain quantity drop into the *kofer*.

FIG. 488.—No. **642**.—More modern type of stamps, in the construction of which there is more metal employed, although the lifters are still of wood. But the bed-plate, the frame, the bottom of the *kofer*, the guides, &c., are of iron.

FIG. 489.—No. **642**.—Modern stamps used at the dressing-floors of Steinenbrück, on the banks of the Rhine. The whole of the machinery is made of iron, including the lifters, which are round and not square as before. The stamp turns a little at each lift on account of the friction between the cam and the tappet, and thus the wear and tear on the head is rendered quite uniform.

The stuff is fed by means of a wheel with blades receiving its motion from the main shaft.

Plate XCVII.—Figures 490 to 494.

Fig. 490.—No. **657.**—This figure shows the details of a separating trommel consisting of two screens—the inner one conical, made of thick sheet-iron, and having large holes, and the outer one cylindrical, or nearly so, made of thinner sheet-iron, and with smaller holes.

The object of this arrangement is to divide the stuff at once into two main classes, and to prevent the coarser fragments from passing on to the thin plates of the fine trommel and wearing them too rapidly.

The sketch *b* shows the manner in which this object is accomplished. Here we have the very common arrangement of a separating trommel supplying two sizing trommels.

The pieces which are too large to pass through the holes in the inner screen of the separating trommel go to sizing trommel 1; those which fail to pass through the holes in the outer screen go to sizing trommel 2; and those which pass through the holes in the outer screen proceed to an ascending-current classifier.

This arrangement is the one usually adopted for sizing gravel and coarse sand.

Fig. 491.—No. **661.**—Herr von Rittinger's pyramidal boxes (*Spitzkasten*) used for classifying fine stuff.

They consist of a series of vats, like the one shown in the figure, arranged so that the overflow of any one box runs into a larger one below it.

The current holding the fine matters in suspension is suddenly checked as it enters each vat; like-falling particles sink down together to the bottom, and then rising through a bent pipe, pass off with a certain proportion of the water to the concentrating machines.

Figs. 492 and 493.—No. **665.**—These sketches illustrate the first attempts that were made to transform the preceding apparatus into one with an ascending current.

If a current of clean water under pressure is allowed to flow in at the bottom of each *Spitzkasten*, it is possible to separate the classes of stuff more distinctly from each other, or even to vary them as desired; the heavier grains fall through the ascending current to the bottom, while the lighter ones are carried over into the next following box. But when the sole change consisted in bringing in water at the bottom of the vat, it was soon found that many of the particles settled down to a point where, in consequence of the decreasing area of the section, the current was too strong to admit of their descending further, and

yet not strong enough to force them up to the level of the overflow and make them pass over into the next vat. The consequence was that before working very long an accumulation of these particles was formed, which seriously interfered with the operation of classifying.

For these reasons a uniform section, cylindrical or prismatic, was adopted in some cases, and a section diminishing upwards in others, as shown in figures 492 and 493.

FIG. 494.—No. **665.**—This figure shows the details of the classifying apparatus employed at Steinenbrück. It is one of the numerous types of upward-current classifiers used on the Continent.

The difficulty referred to above is got over in this case by supplying the current of clean water as a thin sheet, not at the bottom as formerly, but at a certain height above it in the three first compartments. This method is adopted in many dressing establishments.

All the particles which are heavy enough to pass through this moving sheet of water, the force of which is regulated at pleasure by means of stop-cocks, fall to the bottom and are conveyed by pipes to the concentrating machines; the others are carried into the next following compartments, and ultimately discharged.

Plate XCVIII.—Figures 495 to 497.

FIG. 495.—No. **667.**—This figure shows a classifying apparatus used in Belgium, known as the Engis trough. It is based upon the same principles as the preceding one, but is more complicated.

It consists of an inclined trough AA, made of zinc, with the bottom formed of a grating of hollow bars of zinc placed side by side. The shape of each bar is represented in *e*.

These hollow bars are all filled with clean water; they communicate with each other by means of two longitudinal pipes placed below them, which keep them full.

Lastly, the section of the trough increases towards the discharge end. It rests upon the plank partitions which divide the depositing compartments from each other, and communicates with them by the spaces between the bars.

The stuff to be treated is fed in at the upper end of the trough, and runs down in consequence of the slope. The settling compartments LL are filled with water, which runs over from one to the other, and always maintains a higher level than that of the stuff to be washed, and the consequence is that there is always water entering the trough through the bars, thus constituting an ascending current. Only the heavy

grains can overcome this current and pass downwards into the settling tanks, whilst the lighter ones are carried off.

The oblique current of clean water which passes through the slits in the bars shown in *e* supplements the action of the current between the bars. The apparatus itself is complicated in construction, difficult to keep in repair, and has not been much adopted.

FIG. 496 (*a*, *b*, *c*)—No. **669.**—Thirion's washer, another complicated and little used classifier.

The launders for clean water and for ore are placed side by side, and communicate with each other by means of pyramidal boxes on which they rest.

Each of these pyramidal boxes communicates with the clear water launder by a hole which can be more or less opened or closed at pleasure by means of a conical plug attached to a rod with a screw-thread on it; the supply of water can thus be regulated to a nicety. The pyramidal box also communicates with the ore launder by a perforated plate, which permits the ascent of the clear water, and, owing to the difference of level of the streams in the two launders, the descent of the more or less coarse particles of ore. The latter fall into the pyramidal box, and thence into small wooden hutches placed to receive them.

(*d*, *e*, *f*)—Improvements in Thirion's machine, consisting first in substituting a pipe with holes for the conical plug, the rate of flow in this case being regulated by stopping up a greater or less number of the holes, and, secondly, in having slits in the bottom, inclined at an angle of 45° in the direction of the current, instead of the perforated plate.

FIG. 497.—No. **670.**—A sketch showing the arrangement and action of the Dorr classifier.

It consists of a number of small zinc barrels of cylindro-conical shape placed one after the other. The manner in which the stuff is separated will be understood from an inspection of the figure, in which the arrows show the course of the currents.

Plate XCIX.—Figures 498 and 499.

FIG. 498.—No. **671.**—This figure represents the interesting apparatus known by the name of siphon separator (*Heberwäsche*), employed at Mechernich, and it shows the mode of construction adopted at the present time in the workshops of the Humboldt Company.

This separator consists of a wooden box divided into three compart-

ments. The first A serves for bringing in the clear water, which descends below the partition, and finds its way upwards into the adjoining compartment B, in which the separation takes place. It is provided with a perforated plate, the holes of which will allow the water to pass through, but not the grains of ore.

In the centre of the perforated plate is a hole provided with a conical plug leading into the discharge pipe.

The grains which are sufficiently heavy to overcome the ascending current fall to the bottom, and accumulate to such an extent that they soon hinder the free passage of the water upwards. As a consequence the level of the water in the left-hand compartment C rises, lifting the float P, and by means of the lever L this raises the conical valve in the compartment B.

When the mouth of the discharge tube is thus opened, the grains are soon washed out and carried off, the clean water has again free passage upwards through the holes, the level of the water in the compartment C falls, the hole is closed by the plug, and the operation re-commences.

This apparatus is employed at Mechernich for treating quartzose sand containing grains of galena, and it is remarkable for its enormous output, without too great a consumption of water.

Fig. 499.—No. **672.**—Experimental pneumatic classifier, in which perfectly dry and finely-divided ore, fed in by means of the bucket-elevator G and the hopper T, is blown by a fan V into a long box, where it settles down at a greater or less distance from the origin in the order of equivalence according to the law of bodies falling in a fluid.

Plate C.—Figures 500 to 504.

Fig. 500.—No. **678.**—This figure represents the machine known as the hand-jigger, which has been in use from the remotest antiquity, and is still employed in England for the concentration of gravel.

It consists of:

1. A tub or hutch, provided with guides for making the sieve move vertically.

2. A sieve suspended to an iron rod, which receives its motion from a lever.

3. A lever which carries a counter-balance weight at one end for the purpose of rendering the work less severe.

The successive shakes given to the jigging-sieve, either mechanically or by hand, cause the different minerals to settle in layers one above the other in the order of their equivalence.

Figs. 501 and 502.—No. **680.**—These figures represent the theory and the practical realization of the *differential link*. It has been invented for the purpose of giving the piston of the jigger a rapid descending and a slow ascending motion, in order to obtain the reverse conditions of motion for the water contained in the sieve, this being the most favourable state of things for a good classification.

Fig. 503.—No. **682.**—Discontinuous mechanical jigger, with two sieves and piston between them, formerly in use in the Hartz.

The two openings *dd'* shown in the figure can be closed alternately by means of sliding doors. Their position has a great effect upon the regularity of the operation.

These openings occupy the whole width of the partition.

The bottom of the compartment in which the piston works is always horizontal, that of each of the other two is usually inclined towards the openings through which the fine stuff which passes through the sieve is discharged.

Fig. 504.—No. **684.**—Discontinuous mechanical jigger, with the piston underneath the sieve, formerly employed in the Hartz. This position of the piston was intended to obviate difficulties which attended the use of the lateral piston, in consequence of its unequal action on the sieve.

In order to prevent the water from rushing back too suddenly during the descent of the piston, small passages *pp* communicating with the outside were made in the sides of the jigging-tank (*hutch*), in order to allow air to be drawn into the space below the piston while the latter ascended. When the piston descended, on the other hand, the air passed through a central valve S into the space below the sieve, and was thence expelled during the next stroke through the holes *o* in the sides.

Plate CI.—Figures 505 to 509.

Fig. 505 (*a*, *b*).—No. **686.**—This figure represents the newest type of continuous jigger, with two sieves, employed by the Vieille Montagne Company for concentrating gravel of medium size.

The arrangement consists in having two oval discharge openings *o o* in the side at different heights above each sieve, communicating with leaden pipes *t t*. A zinc gutter *z* can be made to block up the end more or less.

The densest particles of ore fall to the bottom and escape by the

lower pipe, while a rich mixture passes through the pipe above. The remainder passes over the partition and falls upon the second sieve, where a similar separation takes place into classes, which are less rich than the first two.

The apparatus is easily regulated by raising or lowering the gutter by means of the wire *f*, and so altering the rate of discharge of the gravel, the operation is thus made to last a longer or shorter time, in order to obtain the desired degree of concentration.

FIG. 506.—No. **686.**—This is a different contrivance from the preceding one, employed at Moresnet for making the jiggers continuous. It consists in having longitudinal slits in the side, instead of the oval holes of the Steinenbrück jiggers, the heights of the slits being varied at pleasure.

FIG. 507 (*a*, *b*).—No. **686.**—Another device, employed at Bleiberg, which consists in having a central tube upon the sieve itself, and discharging-trays at certain heights above it for taking off the more or less concentrated products. The discharge through the tube is regulated by means of a kind of cap, which can be made to shut the opening in the sieve more or less completely, and that of the trays by raising or lowering their inner edges so as to increase or diminish the size of the outlets.

FIG. 508.—No. **686.**—A sketch showing the mode of discharging gravel ore from the continuous *bell-jiggers* at Moresnet.

Discharge-pipes with sliding caps are fixed on the bottom of the sieve; each pipe is provided with a small aperture, situated at a certain height, which allows the gravel to pass out. The outer cap can be raised or lowered at pleasure, so that the concentrate may be collected upon the sieve at such a height as may be desirable. The charge lying on the sieve, for a total height h_1, is constantly pressing the concentrate, whose thickness is h, towards the aperture through which it passes out. The discharge takes place in virtue of the equation:

$$h\ d = h_1\ d_1.$$

FIG. 509.—No. **690.**—This figure represents the Huet and Geyler feeder, which is one of the numerous contrivances employed for ensuring a perfectly regular supply of stuff to jiggers. It is a kind of Archimedean screw, which delivers a certain quantity of stuff at each revolution.

Other feed-regulators are sliding hatches, bucket-elevators, &c.

Plate CII.—Figures 510 to 512.

Fig. 510.—No. **692.**—This figure represents the oldest machine for concentrating sand. It is known under the name of the German buddle.

It consists of a wooden box 11 feet 6 inches to 13 feet (3.^{m}50 to 4 metres) long by about 20 inches (0.^{m}5) wide and deep, with its bottom sloping at the rate of 1 in 12. The lower end, which is vertical, has a number of holes *aa* at different heights. At the upper end there is a shelf upon which the stuff to be buddled is thrown, and lastly a very regular stream of water is provided for bringing it into a state of suspension.

The concentration is effected by continually raking the stuff back towards the head, thereby bringing it into suspension. The richer and heavier particles settle down at the head, while the lighter ones are carried away, and passing through the holes *aa*, fall into the trough *p*, and thence flow on into the slime pits.

Fig. 511.—No. **694.**—Improvement of the last machine by replacing the raking process by a series of mechanical shakes, whence the name percussion-table has been given to this machine.

It consists of a wooden table about 11 feet 6 inches (3.^{m}50) long, provided with upright edges on three sides, and suspended on four chains. The two chains at the head are always of the same length, whereas those at the foot can be wound upon or unwound from a barrel, so as to vary the inclination of the table.

Hung in this way the table receives a succession of blows from the cams of a revolving shaft which act upon a lever, whose head presses against it. After each blow the table returns rapidly backwards and strikes against a firmly-fixed beam.

The shakes have the effect of continually bringing the sand into a state of suspension, and do the work of the rake in a much more economical manner.

The percussion-table will not work properly unless the stuff is thoroughly well suspended in the water, and the orey stream equally distributed over the whole surface of the table. This is effected by means of the slanting rows of buttons *mm* on the head-board, as shown in the drawing.

Fig. 512.—No. **695.**—Concentrating machine known by the name of the round buddle. It is principally used in England, where it is held in high esteem.

It is a shallow cylindrical pit, the bottom of which slopes gently from

the centre to the circumference. The ore-bearing stream arrives in a wooden launder, and passing between two truncated cones, which are constantly revolving, falls upon a central cone.

Hence it flows down over the floor of the buddle, or over the deposit already formed, and the particles of sand settle down according to their densities.

The effect produced in the two preceding machines by raking or shaking is here obtained by the rubbing action of small heather brushes or strips of canvas, which can be raised at pleasure to suit the thickness of the deposit. These rub the surface continually and bring the sand again into suspension, and prevent the formation of small gutters, which would certainly arise but for this action.

The water and undeposited slime escape by openings at the outer edge, and are conducted to the slime pits.

Plate CIII.—Figures 513 and 514.

FIG. 513.—No. **698.**—This figure represents the machine known as the *keeve* or *dolly tub* in England, where it is employed for completing the operation of concentrating.

It is a tub in the shape of a truncated cone, with the sides only slightly inclined inwards, standing on the ground by its smaller end. It is made of wood, and is about 2 feet 8 inches ($0.^{m}80$) high, and at most 3 feet 3 inches to 3 feet 10 inches (1 metre to $1.^{m}10$) in diameter. It is provided with a stirrer composed of two blades on a vertical axis, by means of which the liquid in the tub can be thoroughly agitated.

The stuff is shovelled in round the edge of the tub in small quantities at a time, while the stirrer is in motion. The stirrer is then taken out, and light blows are struck on the side of the keeve; a separation according to density is effected in this manner. The water is baled out, when the top layers of the deposit are found to be comparatively poor, and the bottom ones to be considerably enriched.

This apparatus is by no means so perfect as the next, which is mostly employed on the Continent.

FIG. 514.—No. **699** (*a*, *b*).—This figure represents what may be called the true concentrating machine for sand. It is known as the Hartz jigger.

It is a continuous jigger which differs from those already described by the discharge of the concentrate taking place all over the surface of the sieve.

The sieve, which consists of wire gauze with suitable meshes, is

covered with a bed of grains of equal or superior density to that of the mineral which it is intended to separate, and coarse enough not to pass through the meshes.

At each stroke of the piston the grains of the ore penetrate farther and farther down into this bed, and at length reach the sieve, pass through it, and fall into the hutch below.

All the necessary details of this important apparatus are described in paragraph 699.

(*c.*) This sketch shows how the jigging motion can be regulated by having two excentrics, one fixed on the shaft, the other movable; the length of the stroke can then be varied at pleasure between the sum of the excentricities and their difference.

Plate CIV.—Figures 515 to 517.

FIG. 515.—No. **703.**—This figure illustrates the method of distributing sand employed in the dressing mills at Steinenbrück, on the banks of the Rhine.

The ore-bearing stream is raised by a pump P to the level of a classifier, whence it flows directly to the jiggers or revolving-tables, without time being allowed for any stuff to settle, as this would be prejudicial to the subsequent operations.

FIG. 516.—No. **703.**—This figure represents the centrifugal feeder of Huet and Geyler. A horizontal wheel turning with rapidity sucks up the orey water from the bottom of a conical vessel and sends it to the concentrating machines, while the excess of water and the lighter particles run over the top into a lateral discharge pipe.

FIG. 517.—No. **705.**—This figure represents an air-jigger of recent invention employed in America.

It consists essentially of a charging-hopper T; a sieve *t*, upon which the separation is effected; a lower reservoir R, in which the concentrated ore is retained a longer or shorter time; and lastly a fan E, the rapid strokes of which perform the jigging.

The charging-hopper presents no novel features. A hatch *v*, which can be raised or lowered, enables the amount of feed to be varied at pleasure; whilst a movable edge-piece *v′* regulates the thickness of the layer of ore upon the sieve.

The sieve consists of tubes of wire-gauze open below and at one end, as shown in figure *c.* They are placed alongside each other at greater or less distances apart, according to the size of the stuff under treatment,

the interspaces diminishing as it becomes finer, and they open into the fan-box.

The reservoir R is partially closed at the bottom by a fluted roller r, which can be made to revolve more or less rapidly, and so effect the discharge at any desired speed. The roller is actuated by a lever L placed on the driving-wheel R (figure *a*), which works the fan by means of cams.

This ingenious apparatus may be advantageously employed in hot countries, when the ore can be easily obtained in a state of complete dryness, and when there is a scarcity of water.

Plate CV.—Figures 518 to 519.

FIG. 518.—No. **710**.—Wooden rotating-table of the most common pattern for concentrating slime.

Small radial beams are fixed upon a strong centre-piece of cast-iron, and upon these is first fixed a flooring of deal. A second planking of beech is then carefully nailed on; the planks being arranged radially, joined accurately, and planed till the surface is perfectly even.

The slime is delivered at the centre, and its various constituents flow down the conical surface, and at the same time as the table is carried round the deposit formed upon it comes successively under small jets of water which are continually playing upon its surface. By this means the deposit is washed into one or another compartment of a circumferential launder, according to its degree of concentration.

FIG. 519.—No. **710**.—This figure represents another variety of the rotating table, of more recent date and better construction, employed at Laurenburg by M. Fléchet. It is of cast-iron, made in two pieces firmly bolted together, and turned smooth.

This table deserves notice because its surface remains smooth and even, which is very favourable for the realization of good results.

Plate CVI.—Figures 520 and 521.

FIG. 520.—No. **712** (*a*, *b*, *c*).—This figure represents an important machine for the final treatment of slime known as Rittinger's side-blow percussion-table.

It is generally double, or composed of two tables of marble or hard limestone connected together, and moving simultaneously. This arrangement is not essential, but it economises driving gear. These tables

are fixed upon a strong rectangular frame suspended by chains at its four corners, and are provided with two cross-pieces, which strike against strongly fixed bumping-blocks.

Cams upon a revolving shaft act upon the end of a rod, which pushes the frame with its tables away from its position at rest; it is forced back again by a strong spring as soon as the cam has released the rod.

The slime is delivered at one of the two upper corners of each table, and under the influence of the successive blows its heavier particles are driven by degrees towards the opposite side, ranging themselves according to density upon the surface of the table, in the form of more or less parabolic bands, which terminate immediately above the tanks placed to receive the various products.

FIG. 521.—No. **718** (*a*, *b*).—This figure represents the apparatus known by the name of the *Frue vanner*, which has been employed for some years in America, and has also been tried in England, for the purpose of concentrating sands or slime.

It consists of a large outer fixed frame supporting an inner movable one, which is provided with a series of rollers carrying an endless india-rubber belt with a flange on each side.

The inner frame has a reciprocating side motion imparted to it by cranks fixed upon a shaft running along one side, the stroke being 1¼ to 1½ inch; at the same time the endless belt is made to revolve by means of a drum at one end.

The lighter particles of the finely divided ore are carried down the sloping surface of the belt little by little, being washed down by the current of water, and being kept in suspension by the side shaking, whilst the heavier particles, which resist the current, are carried upwards, and finally, after the belt has passed round the end drum, fall into a tank placed below.

Plates CVII. and CVIII.—Figure 522.

FIG. 522.—Nos. **725** to **729**.—General plan and sections of the Castor dressing-works. The following account will explain the details:

1. Platform where the ore from the mine is received. It rests upon a scaffolding at a higher level than the works; the upright supporting-posts alone are shown in the general plan and section.

2–2. Raised roadway, upon scaffolding at the same level as the last, for tramming the large stuff to the stone-breaker.

3. Stone-breaker, under which is a screen with bars 1¼ inch (32

millimetres) apart; what does not pass through goes to be hand-picked.

4. Large crusher, which receives the stuff that passes through the last screen, and under which there is another screen with $\frac{29}{32}$ inch (23 millimetres) between the bars; what does not pass through is returned to the same crusher.

5. Double-separating trommel with two screens, the inner having holes of $\frac{9}{16}$ inch (14 millimetres), the outer of $\frac{1}{6}$ inch (4^{mm}).

6. Sizing trommel with holes of $\frac{1}{5}$ inch, $\frac{9}{32}$ inch, and $\frac{3}{8}$ inch ($5^{\cdot mm}2$, $7^{\cdot mm}2$, and 10 millimetres).

7. Sizing-trommel with holes of $\frac{1}{20}$ inch, $\frac{1}{12}$ inch, and $\frac{1}{9}$ inch ($1^{\cdot mm}2$, 2^{mm}, and $2^{\cdot mm}7$.)

8–8. Screens, with bars $1\frac{1}{4}$ inch (32 millimetres) apart, which receive the small stuff (*smalls*) from the mine. What does not pass through is hand-picked.

9–9. Separating-trommels, the same as trommel 5, except that the inner screen has holes $\frac{29}{32}$ inch (23 millimetres) in diameter. What fails to pass through this inner screen is taken by an elevator to the level of platform 2–2, and thence to the crusher 4.

10–10—10–10. Sizing-trommels, the same as 6, 7.

11. Shed for cobbing and picking the lumps which are larger than $1\frac{1}{4}$ inch (32 millimetres); the gravel between $1\frac{1}{4}$ and $\frac{29}{32}$ inch (32 and 23 millimetres) goes back to the crushing rolls 4.

12. Intermittent jigger, for gravel between $\frac{29}{32}$ and $\frac{1}{2}$ inch (23 and 12 millimetres).

13. Intermittent jigger, for gravel between $\frac{1}{2}$ and $\frac{3}{8}$ inch (12 and 10 millimetres).

14–14. Continuous jiggers, with two sieves and four discharge pipes, exclusively for gravel between $\frac{3}{8}$ and $\frac{1}{20}$ inch (10 millimetres and $1^{\cdot mm}2$).

15. Medium-sized rolls, for crushing the coarsest *dradge* (mixed ore and waste) produced in the preceding jiggers.

16. Separating and sizing trommels, for sizing the crushed product from these rolls.

17. Fine rolls, for crushing the other *dradge* produced by the jiggers 14.

18. Sizing-trommel, for sizing this crushed *dradge*.

19. Centrifugal pump, receiving all the products of $\frac{1}{20}$ inch ($1^{\cdot mm}2$) and less suspended in water, and raising them to the level of the classifier.

20. Classifier with ascending current, having six compartments.

21–21. Hartz jiggers, receiving and treating the products of the classifier.

22. Hartz jigger, for re-jigging the waste from the preceding jiggers,

from time to time, and so checking their work, and also for estimating the loss in this waste, and seeing whether there is any necessity for altering the mode of working.

23. Second classifier, with eight compartments, receiving the overflow from the first.

24. Revolving tables, each fed with the products of two compartments of this classifier. The overflow goes to the slime-pits.

25. Boilers.

26. Horizontal engine of 40 horse-power.

Plate CIX.—Figures 523 to 528.

Fig. 523.—No. **729.**—Sketch showing the East Pool tin dressing-floors in Cornwall.

The principal thing to be remarked here is the complete difference between the methods and machines in use in this establishment and those employed on the Continent.

A A A are stamps for crushing the ore, which is finely disseminated in the veinstuff. The stamped ore flows into the strips B B B, where the heavier particles are deposited, while the lighter ones are carried into the slime-pits *aa*.

The former are treated in a series of concave round buddles (1, 2, 3, &c.). or convex ones (R_1, R_2, R_3), while the latter go to the frames FF.

At this stage of the dressing the concentrate is subjected to a first roasting in the calciners C C, in order to transform the sulphides into specifically lighter oxides. A new series of operations is then gone through, terminated by a second process of roasting. Lastly, the washing is continued on the round buddles 17, 18, &c., and the dressing is finally completed in the kieves *c*, *c*, *c*.

The details of the operation are given in the table on pages 131–133, to which we refer the reader.

Fig. 524.—No. **781.**—This figure represents Bazin's pipette, which is used for taking samples of auriferous sand from the bottom of a river.

It is a hollow ovoid copper vessel, fixed at the end of a long pole. It can be driven down into the wet running sand, and the bottom opened or shut at pleasure, by means of a ball attached to a long cord.

When the pipette has been forced down, the hole is opened by drawing out the ball; the hydrostatic pressure then forces sand and water into it, the ball is once more drawn back, and the pipette withdrawn with the sample.

Fig. 525.—No. **733.**—Bazin's centrifugal hydraulic washer.

This machine consists of a cylindrical tank of sheet-iron filled with water, with a vertical iron rod in the centre supporting a washing bowl made of copper.

When the washing-bowl is made to revolve, the centrifugal force causes the lighter particles to rise to the edge of the bowl, where they fall over and then sink to the bottom of the tank; while the heavier particles, and notably the scales of gold, remain lying upon a movable dish, which can be easily lifted out. They are then washed in a *batea*.

Fig. 526.—No. **734.**—Contrivance known as the cradle, and employed in America and Australia for gold-washing.

It is a rectangular wooden box, about 3 feet 3 inches (1 metre) long by 20 inches (0·50 metre) wide, open at one end, closed at the other, and resting on two rockers, like those of a child's cradle, which enable it to be moved to and fro about an axis parallel to its longer sides.

At the upper end there is a movable hopper, the bottom of which is made of perforated sheet-iron.

The perforated plate keeps back the coarse gravel, while the finer particles pass through and fall upon an inclined canvas apron. The scales of gold are caught either by the canvas or by riffles nailed on the bottom.

Fig. 527.—No. **735.**—This figure represents the section of a *sluice box*, a long trough or launder, which is largely used in California for catching gold from auriferous alluvia. It will be necessary to refer to paragraph 535 for further details concerning this mode of working.

Fig. 528.—No. **737.**—Bazin's mercurial washer has some similarity to his hydraulic washer, in so far that centrifugal force is made use of, but it differs in this respect, that the sand is brought in at the bottom by a vertical pipe, and rises upwards through a column of mercury which retains the scales of gold, partly in consequence of their higher density, partly through chemical affinity which causes them to amalgamate with it.

Plate CX.—Figures 529 to 532.

Fig. 529.—No. **744.**—A sketch representing a portion of the sizing machinery of the anthracite breaker at Drifton, in Pennsylvania. The whole breaker is shown in figure 542.

The coal passes in the first place on to screens with cast-iron bars A $5\frac{1}{2}$ inches (14 centimetres) apart. Their ends rest in notches in the

cast-iron frame which surrounds them, but in such a manner as to permit their distance apart to be varied.

The coal which passes over the screen falls between rolls B, and thence into a trommel C composed of two screens with square holes 2½ and 2 inches (0.^{m}063 and 0.^{m}050) on the side respectively.

Whilst the two larger sizes pass on to shoots, where they are picked by hand before being sent to the market, the smaller pass into a second trommel D with square holes of 1⅛ inch and ¾ inch (0·^{m}029 and 0·^{m}019) on the side, &c.

This figure, which represents only a small portion of the establishment, gives an idea of the length to which sizing is pushed for this special quality of fuel.

FIG. 530.—No. **745.**—Rolls for crushing anthracite. They differ from the common rolls, represented in figure 485, only by the addition of the cast-steel teeth fixed over the whole surface of the shells. A tooth can be easily replaced when broken, after driving the stump or shank into the interior of the shell by means of a punch.

These rolls are connected by toothed gearing, and this necessitates the presence of a *breaking* or *safety piece* B, which will give way in the event of any foreign substance becoming jammed between the teeth.

Lastly, the cylindrical form of the plummer blocks should be observed; the object is to prevent the shaft from being bent if an accident should happen.

FIG. 531.—No. **746.**—Conical mill for crushing coal. This machine consists of two upright toothed cones, one movable and standing within the other, which is fixed. The fragments of coal are seized and crushed between them, and escape by the lower opening.

In order that the pieces may be caught properly, and crushed between the two conical surfaces, it is necessary that the teeth of the moving cone make a certain angle with those of the fixed one, and in practice this is is generally 5° or 6°, as shown in figure *a*, which represents the development of part of the conical surface.

Suitable arrangements permit of the axle being properly centred and raised if necessary to the required height.

FIG. 532.—No. **746.**—This figure represents a section of Carr's disintegrator. It consists of two iron discs, cast each in one piece with its hollow axle, which revolve at a great velocity, in opposite directions, on a fixed shaft made of hard steel.

The two discs are completely enclosed in a sheet-iron case, and each of

them carries two circles of steel bars, joined together at their free ends by wrought-iron rings to which they are screwed.

The coal, which is supplied from a hopper on one side, should not be above a certain size. It is caught by the bars and subjected to a succession of blows which pulverize it finely, and it soon falls into a receptacle placed under the machine.

Plate CXI.—Figures 533 and 534.

FIG. 533.—No. **749.**—This figure represents the Molières washing-machine, which is nothing but an improved piston-jigger.

It consists of a long wooden tank fitted with a slightly-inclined sieve, on which the charge lies. The piston, P, floats on the surface of the water, and its area is half that of the tank.

This tank is divided by partitions into three compartments communicating with each other. The first and most important one, A, is that in which the coal is jigged. The raw coal is fed on regularly by a roller placed at the bottom of the charging-hopper, and falling in a continuous shower at one end is thus immediately wetted before it can form clots or lumps. It then moves along gradually to the other end, and is classified on the way. The clean coal which falls over the end into a transverse launder is carried away by an endless screw V. The shale, on the other hand, passes through an orifice, with a sliding hatch, a little higher than the sieve, into the second compartment C, whence it is raised by a bucket-elevator.

The sludge falls to the bottom of the tank, from which it can be removed without interrupting the operation.

FIG. 534.—No. **750.**—This figure represents the Grand-Combe washing-machine. It is also a piston-jigger, but differs rather more from the original type than the preceding one.

The tank is fitted with two sieves having a bed of gravel between them. The effect of this is to regulate the action of the water upon the sieve, and also to diminish the suction of the returning water, and consequently the resulting loss of sludge.

The coal is fed in at the head of the machine by a hatch that can be opened at pleasure, which allows a certain quantity to sink down upon the sieve at each stroke of the piston.

The clean coal is carried over the tail end, and is drawn away by an endless screw. The shale is removed by a shovel from time to time, but the operation of washing has to be stopped for this purpose.

In this case the piston does not return freely to its original position,

but is drawn back by an excentric. This arrangement would cause very mischievous eddies, if provision had not been made to guard against this evil by the *safety bed* which we have described, and by reducing the speed of the piston to twelve strokes per minute; but at the same time the length of the stroke has been increased so as to raise the charge effectually.

Plate CXII.—Figure 535.

FIG. 535.—No. **758.**—This figure represents the machine known by the name of *Bérard's coal washer.*

It consists of two parts—one for classifying according to size, the other for crushing, properly so-called.

The sizing is effected by means of perforated sheet-iron screens one above the other, which are shaken backwards and forwards at the rate of 150 to 180 times per minute. They are fed by a bucket-elevator G G, which lifts the coal out of a pit. In the case of clayey and wet coal this operation can be assisted by a stream of water, which prevents the holes from becoming choked. The screens separate the stuff into two or three classes, which are distributed separately to the piston-jiggers B B B, which constitute the washing-machine properly so-called.

The jigger tanks are made of cast-iron, one part of the bottom being inclined at an angle of 45°, the remainder being level. A cylinder cast in one piece with one of the plates stands on one side, and serves as a working barrel for the piston *p*. It opens into the rectangular tank about half-way up, and is enlarged in the bottom at its junction with the flat side, in order to make up to some extent for the small dimensions of the piston.

In this apparatus the ingenious arrangements for removing the products automatically deserve special attention, as well as the method of hindering the formation of sludge.

The automatic removal of the products is effected as follows:

The pieces of shale escape through the opening between the hatch *v* and the flange *v'*, in exactly the same way as the ore does in the Moresnet bell-jiggers.

The coal is carried over the end of the jigger on to an inclined tray, *i i*, either by the stream of water, or in consequence of the constant pressure of the descending charge at the head.

In the former case it is necessary to keep up a constant supply of a considerable quantity of water through the pipe *t t*. The coal drains itself more or less upon the inclined tray *i i*, according to the size and number of the holes in it, and thus retains more or less of the dust with which it is mixed.

In the latter case the perforated plate of the inclined tray is replaced by a plain plate, and the withdrawal of the coal is effected with the aid of a hatch and flange, between which a sort of decanting action takes place, which again prevents the loss of sludge to some extent.

Plate CXIII.—Figure 536.

FIG. 536.—No. **761.**—This figure represents one of Évrard's classifying and washing machines, designed for treating 200 tons a day.

It consists of a cylindrical or rectangular tank C, 23 to 26 feet (7 to 8 metres) deep, with a horizontal sectional area of 54 to 64½ square feet (5 or 6 square metres). Near its bottom it communicates by a pipe t with a second tank called the *piston-tank*, which is not so high, but has the same horizontal section; both tanks are more or less completely filled with water. At a depth of about 6 feet (2 metres) below the upper edge of the first tank there is a frame covered with a perforated plate of sheet-iron intended for carrying the charge (about 4 tons).

The second tank is hermetically closed, and when a sufficient amount of pressure is exerted on the surface of the water contained in it, the water flows through the communicating pipe t, and, passing through the perforated plate, raises the charge.

The pressure is obtained from a steam pipe t', which communicates with the top of the tank.

The charge lying on the perforated plate is classified by the upward movement of the water, and the effect is increased by turning on an extra amount of steam several times in succession by means of a special cock. The charge is afterwards raised in successive stages by means of a hydraulic piston in the cylinder C′, and divided into several classes, such as sludge, clean coal, mixed shale, &c., by means of a mechanical slicer worked by the hydraulic cylinder P.

The slimy water runs into a large settling-tank with compartments in which the fine particles settle, whilst the water returns to the machine.

Plate CXIV.—Figure 537.

FIG. 537.—No. **762.**—This figure represents Marsaut's washing machine recently erected at Bességes. It consists of the following parts:

1. A wooden tank of rectangular section, open at the top and closed at the bottom by a horizontal partition provided with sliding-doors, which separates it from a reservoir in which the sludge is deposited.

2. An iron cage with guides, the bottom of which is formed like an ordinary jigging-sieve. The sides consist of three separate horizontal

sections, like drawers without bottoms, which can slide upon each other in such a way as to cut off the charge at their level, and make it fall into special hoppers prepared for its reception. The cage is suspended at the end of a rod, attached to a piston working in a long cylinder filled with water under pressure.

3. A lateral overflow reservoir, which prevents great variations in the level of the water while the cage is being charged. Underneath it there is a return-pipe, provided with a floating-valve, which allows the water above the charge to find its way back into the space below the cage during the ascent, but prevents the water from passing in the opposite direction during the descent.

4. A series of suitable hoppers for charging the raw coal, and receiving the washed products.

Full details of the process of washing will be found in paragraph 762 of the text, and the exact situation of the various parts of the machine is pointed out in the description of fig. 541.

Plate CXV. and CXVI.—Figures 538 and 539.

FIG. 538.—No. **768**.—This figure is intended to give an idea of the coal-washing works at the Grand-Combe.

The works consist of a numerous series of jiggers ranged under a shed, which is represented in sectional elevation in fig. 538.

The waggons filled with small coal coming from the mine arrive upon a platform about 10 feet (3 metres) above the level of the jiggers, and are tipped on to fixed screens with bars ¾ inch (2 centimetres) apart. The part that passes through between the bars falls into large hoppers; the coarser lumps are picked by women and children.

After the washing has been completed, the washed coal, as we saw in paragraph 750, is conveyed by an Archimedean screw, which serves four machines, into a pit, which also receives the products of other four washing machines arranged symmetrically on the opposite side (fig. *a*). This convenient arrangement of bringing together the products of eight jiggers to one point enables various qualities of coal to be collected successively. At first, immediately after the removal of the shale from all the eight jiggers, we get very pure coal, *i.e.* coal with a very small percentage of ash, and afterwards coal with an increasing amount of ash until the normal percentage is reached. This plan renders it easy to satisfy the various requirements of the consumers.

The washed coal is lifted out of the pit by a bucket-elevator, and loaded into waggons; the shale is removed by hand from time to time, and thrown away.

FIG. 539.—No. **769**.—This figure, which is divided into several parts, and extended over two plates, represents the Molières works for coal screening and washing. They belong to the Bességes Coal Company.

The following description will explain the various details:

75. Belleville boiler of 40 horse-power, supplying two steam engines.

76. Engine that drives the trommels, the hydraulic pumps (pressure of 64 pounds per square inch, or 4½ k. per square centimetre), and the jiggers; effective pressure of steam 42½ pounds per square inch (3 k), diameter of piston 13¾ inches ($0^{\cdot m}35$), stroke 1 ft. 11½ in. ($0^{\cdot m}6$), 33 revolutions per minute, 17¾ horse-power (18 chevaux-vapeur).

Screening department.

77. Point at which the raw small coal arrives.

78. Hydraulic tipper.

79. Hoppers for supplying trommels, or revolving screens.

80. Single-screen trommels (15 to 16 revolutions per minute).

81. Eggs of 1½ inch (4 centimetres) and over, raised by the lift γ to the picking-floors, whence they are taken to the market.

82. Nuts of 1 inch to 1½ inch (2½ to 4 centimetres) raised by the lift γ to a modified Bérard washing machine, not shown in the figure.

83. Screened small of 1 inch (2½ centimetres) and under, going by a bucket-elevator to the washing department.

Washing department.

84. Hopper for screened small.

85. Waggons of a capacity of 25 cubic feet (16 hectolitres) supplying the hoppers of the washing machines; they have sliding bottoms.

86. Hoppers of the washing machines.

87. Large piston-jiggers.

88. Shaft actuating the excentrics (33 revolutions a minute).

89. Gear for working the piston.

90. Screw for stopping the piston.

91. Roller for feeding the coal to be washed.

92. Screws for conveying the washed small to the bucket-elevator.

93. Bucket-elevators for raising the washed coal.

94. Transmission of power to the elevator for raising the washed coal from two machines.

95. Hoppers for the washed coal.

96. Compartments in which the coal containing bands of dirt is separated.

97. Hoppers into which this kind of coal is shovelled.

98. Compartments for shale.

99. Bucket-elevators for raising the shale.

100. Shaft driving these elevators, and the rollers for feeding the screened small.

101. Hopper for shale.

102. Hatch for withdrawing the sludge by means of shovels.

103. Hopper, with sliding-door, for the mechanical removal of the sludge.

104. Passage by which the sludge is removed.

105. Pipe for supplying water to the jiggers.

106. Cock for emptying the tanks.

Plate CXVII.—Figure 540.

FIG. 540.—No. **770**.—This figure represents the Roche-la-Molière works, where Évrard's classifying washer of the most recent construction is employed.

The situation of the various machines in the works is shown by numbers as follows:

1. Hopper in which all the coal which has passed through a screen of $1\frac{1}{5}$ inch ($0^{m}.03$) between the bars is mixed together. (There are two of these hoppers, but one hides the other in the drawing.)

2. A trommel, with bars $\frac{2}{5}$ inch ($0^{m}.01$) apart, for separating the nuts. The coal is lifted to this level by a bucket-elevator.

3. Shoot for conveying the stuff which will not pass No. 2 into No. 4 trommel.

4. Trommel for classifying the nuts into 2 sizes—$\frac{2}{5}$ to $\frac{4}{5}$ inch and $\frac{4}{5}$ to $1\frac{1}{5}$ inch (1 to 2 and 2 to 3 centimetres).

5. Storage for the nuts, which are either sold or washed in an old Évrard machine.

6. Hopper receiving the stuff which passes between the bars of No. 2 trommel.

7. Measuring-box.

A. Évrard's classifying washer.

8. Shoot which enables raw coal to be mixed with the washed coal, by letting the former run over from the hopper 6.

9. Scraper for cutting off the slices of washed coal.

10–10. Cocks for sending the water under pressure to the piston which works the scraper, or to the piston which raises the washing-table.

11. Levers and shaft, which actuate a distributing-cock; they are moved by a hydraulic piston.

The distributing-cock enables the stuff coming from the washing-tank to be sent in any one of five different directions.

First direction, for the water containing sludge

12–12. Launder carrying the water to the settling-tank.

13. Settling-tank.

14. A cone, which is excentric in regard to the settling-tank. The sludge is drawn into it by means of scrapers moving round a vertical axis, and allowed to drain.

15. Pit from which the sludge is again lifted by a bucket-elevator, and taken to the hopper (16), where it is mixed with the washed coal.

Second direction, for the slices of washed coal.

16. Hopper into which the washed coal is pushed by the scraper (9).

17. Revolving table for letting the water drain off and for mixing the coal.

18. Shoot which conveys it to the Carr's disintegrator.

19. Carr's disintegrator.

20. Hopper into which the washed and ground coal falls.

21. Shoot into which it is lifted by a bucket-elevator.

22. Large draining-chambers, two in number, being together 59 feet long by 46 feet wide (18 metres by 14 metres).

23. Small waggon for conveying the coal to the coke ovens.

Third direction, for the mixed stuff.

24. Shoot into which the mixed stuff is pushed by the scraper.

25. Pit from which a bucket-elevator, at right angles to the plane of the drawing, lifts the mixed stuff to a circular washing-machine on Évrard's old system, not shown in the figure.

26. Platform receiving the washed coal from the preceding machine.

27. Small waggon for receiving the stones and refuse from the same machine.

28. Shoot into which it is pushed.

Fourth direction, for the composite stuff (coal with adherent shale).

29. Hopper, shown by dotted lines, receiving the composite stuff.

30. Shoot to which it is raised by a bucket-elevator, and which conveys it to the disintegrator (31).

31. Carr's disintegrator. The broken stuff falls into the pit which receives the raw coal.

Fifth direction, for the stones.

32. Shoot for carrying off the stones, which fall into a small waggon.

The third and fourth directions are not used unless coal containing less than 10 per cent. of ash is required. In ordinary work the upper slices only are removed, and the remainder of the mixed stuff is left in the tank during several operations.

Plates CXVIII. and CXIX.—Figures 541 and 542.

FIG. 541.—No. 771.—This plate shows several sections of the washing works at Bessèges, belonging to the Bessèges Coal Company, and following is the description of its various parts:

Belleville boiler of 40 horse-power, supplying steam to four engines.

a. Hydraulic lift or hoist with two balanced pistons. (The water acts under only one of these pistons, which is weighted in such a manner as to enable it to raise the other piston with its load automatically.)

δ. Simple hydraulic hoist.

ω. Hydraulic hoist for the sludge.

1. Engine which drives the trommels and the force-pumps. (Effective steam pressure 42·6 pounds per square inch (3 kilogrammes per square centimetre); length of stroke, 1 foot 7½ inches (0·m50); diameter of piston, 11¾ inches (0·m3); velocity, 35 strokes per minute; 14 horse-power.)

2. Pumps which force 353 cubic feet (10 cubic metres) of water to a height of 380 feet (116 metres) per hour.

3. Reservoir for supplying the pumps.

4. Air chamber for the pumps.

5. Pipes for conveying the water under pressure.

6. Hoist. (Steam engine with two cylinders. Diameter of piston, 8 inches (0·m2); stroke, 8 inches (0·m2); speed, 150 revolutions per minute; 12 horse-power.)

Screening arrangements.

7. Waggon bringing the raw small coal.

8. Waggon being tipped.

9. Empty waggon returning to the mine.

10. Hydraulic tipper.

11. Hopper for feeding the coal to the revolving screens.

12. Trommel with two concentric screens (15 to 16 revolutions per minute).

13. Screens with bars 2 inches (5 centimetres) apart.

14. Table for picking the large nuts.

15. Waggon for the large nuts of clean coal raised by the hoist δ to the floor for deposits of marketable coal.

16. Waggon for large nuts containing bits of shale (to be freed from shale or given to the workpeople gratuitously).

17. Waggon for stones.

18. Hopper or bin for small nuts of 1½ to 2 inches (4 to 5 centimetres).

19. Vertical sliding doors.

20. Waggon for small nuts which are raised by the hoist to a special picking place.

21. Bin for small nuts of $\frac{3}{4}$ to $1\frac{1}{2}$ inch (2 to 4 centimetres).

22. Waggon for small nuts ($\frac{3}{4}$ to $1\frac{1}{2}$ inch) going to the hoist.

23. Shaking screen making 140 oscillations of $4\frac{3}{4}$ inches (12 centimetres) per minute.

24. Bin for peas of $\frac{5}{8}$ inch to $\frac{3}{4}$ inch (15 to 20 milimetres).

25. Waggon for peas going to the hoist.

26. Bin for fine stuff less than $\frac{5}{8}$ inch (15 milimetres).

27. Waggon for fine stuff going to the hoist.

28. Horizontal sliding doors.

Special picking room for small nuts.

29. Waggon containing small nuts brought up by the hoist *a*.

30. Screens with square holes of $1\frac{1}{4}$ inch (3 centimetres) on the side.

31. Cast-iron tables on which the nuts are picked, and on which the coal containing bits of shale is broken by hammers; it has square holes of $1\frac{1}{4}$ inch (3 centimetres) on the side.

32. Benches for the pickers.

33. Waggons for the picked nuts.

34. Waggons for the stones.

35. Hopper holding the small coming from the second screening of the nuts and from breaking the pieces containing shale by hammers.

36. Waggon going to the drums by the elevator *a*.

Old piston-jiggers worked by machinery.

37. Arrival of the screened small.

38. Revolving tipper.

39. Hopper with horizontal sliding doors for receiving the screened small.

40. Waggon holding 70 cubic feet (20 hectolitres), with sliding doors in the bottom for conveying the small coal to the old piston-jiggers.

41. Bin for storing the screened small.

42. Hoppers for feeding the piston jiggers, provided with horizontal regulating hatches.

43. Twin piston-jiggers.

Marsaut's washing machines. (Plate cxiv.)

44. Waggon with the screened small.

45. Revolving tipper serving the two washing machines.

46. Empty waggon returning to the hoist.

47. Charging hopper; the charges vary from 106 to 212 cubic feet (3 to 6 cubic metres).

48. Sliding door for letting the charge fall into the cage.

49. Shutter for guiding the charge as it falls.

50. Water-tight tank made of oak planks $2\frac{1}{3}$ inches (6 centimetres) thick.

51. Cast-iron bottom provided with sliding doors.

52. Reservoir by means of which the sludge can be withdrawn without stopping the washing.

53. Cast-iron trap-door giving access to the sludge chamber. This door is raised and lowered by means of a fixed tackle, and is tightened by means of wedges.

54. Washing cage, having three horizontal compartments or drawers—one for the washed coal, one for the coal that requires to be washed over again, and one for the shale.

55. Opening with a hatch for letting out the water that remains on the top of the charge after the operation of washing has been completed.

56. Hydraulic cylinder with piston attached to the washing cage.

57. Pipe bringing in the water under pressure.

58. Valve for turning on the water under pressure which works the washing cage.

59. Water meter which regulates the drops of the cage from $\frac{3}{4}$ inch to 8 inches (2 to 20 centimetres).

60. Lever for working the water meter.

61. Overflow reservoir, which prevents great variations in the level of the water while the cage is being charged.

62. Wire-gauze filter.

63. Pipe for letting the water flow from the top of the cage back again to the bottom, but provided with a floating valve, which prevents a current in the opposite direction.

64. Bolt for stopping the cage while the different drawers are being emptied.

65. Double-acting hydraulic ram, which pushes out and draws back the different drawers of the cage.

66. Lever for working the ram.

67. Hopper for the washed coal.

68. Hopper for the coal requiring to be rewashed.

69. Hopper for the shale.

70. Waggon with washed coal, which is raised by the lift *a* to the level at which the marketable products are stored.

71. Waggon with coal to be re-washed, returning to the washing-machine on the elevator.

72. Waggon with shale.

73. Pipe for supplying water to the washing-machines and valve.

74. Tank which receives water that escapes from the hydraulic engines and returns it to the force pumps.

FIG. 542.—No. 772.—This figure represents in a general manner a plan and elevation of the *breaker* or establishment for the mechanical preparation of anthracite, situated at Drifton, in Pennsylvania.

The pieces of timber with which it is built are shown by means of single lines for the sake of greater simplicity.

The principal machines which serve to effect the classification are represented by the letters under which they are described in detail in the table at page 182. We must complete that description by adding:

aa is the inclined plane by which the lines of railway coming out of the mine are continued into the breaker.

β is the position of the tipper which discharges the anthracite on to the first screens, whence it descends through a more or less numerous series of other screens and rolls, until it arrives at the shoots (*chutes*, U.S.), or loading hoppers (*pockets*, U.S.).

$\gamma\gamma\gamma$ are shoots in which the anthracite is picked by hand.

δ is a washing trommel (*mud-screen*, U.S.).

$\sigma\sigma\sigma$ are hoppers (*pockets*, U.S.) for storing the various classes of anthracite.

The shaking screens are not represented in this sketch, the principal object of which is to show the sequence of the operations for classifying according to size, and in this example these operations are developed to a remarkable extent.*

* A better figure and account of the Drifton *breaker* will be found in *Engineering*, vol. xxxvii. pp. 164 and 311. London, 1884.

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